EFFECTS OF AUTOMATION ON AIRCREW WORKLOAD AND SITUATION AWARENESS IN TACTICAL AIRLIFT MISSIONS

THESIS

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Abstract

In tactical aviation, decision superiority—brought upon by high situation awareness—remains the arbiter of combat effectiveness. The advancement of sophisticated avionics and highly automated cockpits has allowed the reduction of aircrew size, and in certain platforms, removal of the crew from the aircraft entirely. However, these developments have not reduced the complex and dynamic interaction between situation awareness and crew workload. While many predictive and experimental methods of evaluating workload exist, situation awareness can only be measured by conducting trials with human operators in a functional prototype. This thesis proposes an innovative methodology to predicatively determine situation awareness potential with discrete-event simulation software. This methodology measures situation awareness as both a function of task accomplishment and workload experienced. Utilizing two common but complex tactical scenarios, this method and existing workload measurement techniques can facilitate a direct comparison between a reduced-crew highly automated cockpit and a less automated "legacy" aircraft. Finally, conclusions regarding the effectiveness of replacing human operators with automation in tactical events can be made which can be tested in future experiments with actual aircraft and aircrews.

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To my family, who I owe a lot of quality time.

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I. Introduction

General Issue

With the advent of new avionics technologies amidst an aging fleet of aircraft, many platforms are undergoing Avionics Modernization Programs (AMP) or block upgrades that eliminate crew positions that were integral in the original design. For example, the Navigator and Flight Engineer were common in the previous generation of many multi-crew aircraft, but are eliminated in current designs. The C-130 family, from the C-130E/H, to the AMP, to the C-130J and various special operations variants are prime examples of variable crew compliments currently in operation. The advent of Remotely Piloted Aircraft (RPA) weapon systems takes this design evolution another dramatic step forward by removing the crew from the aircraft entirely, replaced by a wireless connection. Furthermore, while most airliners operate with a two-person cockpit, the industry is beginning to study the efficacy of a one-pilot cockpit (Press Association, 2010). Similarly, the Defense Advanced Research Projects Agency (DARPA) is developing a multi-mission-capable autopilot to reduce a mission crew to just a pilot-supervisor (McDuffee, 2014).

This inevitable march towards smaller crew compliments has several recognizable benefits: reduced training costs as pipelines are closed or reduced, less money spent on aircrew salaries, fewer avionics installations required, easier crew scheduling in operational units, simplified Crew Resource Management (CRM) from fewer voices in

the cockpit, and decrease in aircraft basic operational weight leading to improved aircraft performance. However, simply deleting a crew position is not without risks. Fewer people on-board can increase workload demands of those that remain to the point of overload if cockpit design and procedures are not adjusted accordingly. Aircrew specialization disappears as more tasks merge under the pilots' responsibilities, thus the pilot must maintain a general level of expertise in the aircraft's complex systems, tactics and procedures, and has fewer avenues to outsource tasks.

Not only is crew size affecting pilots' responsibilities, but mission sets have evolved after the aircraft enters production. The C-130 has evolved into airborne firefighting, aerial spraying, helicopter air refueling, and gunship since its first flight in 1954. Even in traditional mission sets, such as airland and airdrop, operational units find new tactical applications and employment methods that may not be clearly elicited originally. For example, the advent of surface to air missiles (SAMs) have driven the C-130 to train in the low-level environment, add defensive systems, and train aircrew on lookout doctrine, thus adding more responsibilities for the aircrew (AFTTP 3-3.C-130E/H, 2010).

Aviation is a highly dynamic environment, where weather, malfunctions, and aircraft emergencies can quickly increase aircrew workload past the point of task saturation. Nowhere is this more demanding than in the tactical environment. Mission events such as low-level/terrain following navigation, unimproved/battle damaged runway operations, Night Vision Goggle (NVG) usage, chemical warfare defense, weapons employment, airdrop/aerial delivery, air combat maneuvering, and threat avoidance/defensive maneuvering create a much more demanding and unpredictable

profile than the airline industry, yet incorporate more numerous systems, design limitations (i.e. low thrust-to-weight ratio), or other factors that do not neatly fit into research conducted for single-seat fighters. Similarly, agility must be programmed into tactical airlift to develop the fledging on-call airdrop, emergency aeromedical evacuation, Search and Rescue (SAR), and to a lesser extent, humanitarian relief mission sets.

Problem Statement

Mission effectiveness is driven by decision superiority. Decision superiority is best modeled through Col John Boyd's Observe-Orient-Decide-Act (OODA) loop. The combatant that can loop the quickest with the most accuracy is the most successful and has achieved decision superiority (Osinga, 2006). While the OODA loop was first created for air-to-air combat in single seat fighters, it can readily be applied to highly random environments. Decision superiority drives mission effectiveness in such things as: success on the first pass on the drop zone or landing zone, responsiveness to time critical situations, or simply aircrew survivability. First pass success is considered one of the most important criteria on tactical missions (AFTTP 3-3.C-130E/H, 2010). This agility is a function of an aircrew's ability to process vast amounts of disparate information, form a coherent picture (known as situation awareness), and act decisively in a coherent manner. SA is dependent on the ability of human operators to manage their workload effectively. Workload management is most demanding in an unpredictable combat environment: when the aircrew is simultaneously communicating on multiple radio frequencies to disparate agencies, scanning for threats, with aircraft malfunctions while completing tactical tasks in response to mission events.

Automation, by changing the nature of human interaction with the machine, must also change the operator's ability to comprehend and react to the environment around him or her. This can be even more significant when automation replaces a human operator that was once part of a larger team. As a result of increased automations, its effects on pilot workload and situation awareness in tactical airlift missions are unknown.

Research Question

Does advanced cockpit automation provide the aircrew with reduced workload and enhanced situation awareness during tactical mission events?

Research Focus

The primary case study is the conventional C-130 fleet (both H and J variants). The C-130 is an ideal platform for this case study because it has been in continuous production for over 55 years, and thus has been through numerous avionics modifications and crew-size transformations which has produced a number of case studies and provided a significant collection of mission data.

This thesis will focus on the crew and configuration of the cockpit, as well as the effect the configuration of these elements on crew workload and situation awareness (SA) in events not commonly found in the commercial airline industry. This research provides analytical computer simulation of workload differences in typical C-130 missions, comparing both H and J aircraft. Furthermore, this research creates a novel methodology to quantitatively predict potential SA in a manner that facilitates direct comparison between two systems. From this simulation output, situation awareness theories can be

applied to extract how much mental capacity remains for the crew to maintain high team SA. As a result, the reader will understand how the highly automated C-130J with its reduced crew size experiences workload and SA differently than the less automated C-130H and its larger aircrew.

Investigative Questions

1. How does the use of automation affect workload during a Station Keeping Equipment (SKE) formation airdrop mission?

By modeling existing operation procedures and inputs from external stimuli (i.e. radio communications to ATC agencies), it may be possible to observe and predict workload levels through computer simulation. Design of these systems have different impacts on the timing, duration, and intensity of high workload periods. Modifying the crew compliment or cockpit design alters the balance of roles and responsibilities that changes how tasks are shared. This rebalancing shifts workload peaks in both magnitude and timing. Specifically, the C-130H requires the Pilot to manually fly the aircraft while in formation, while the C-130J has the ability to maintain its formation position with the autopilot coupled. Furthermore, the C-130H crew must relay formation commands via push-button while the C-130J can do this automatically. **Hypothesis:** Automated cockpits result in lower workload than non-automated cockpits during formation airdrop.

2. How does automation affect aircrew situation awareness during a SKE formation airdrop mission?

An aircrew experiencing too much workload loses situation awareness as task demands consume mental resources. The correlation between situation awareness, task accomplishment and workload must be examined. Using the workload analysis from the

previous investigative question, a situation awareness (SA) algorithm can be created to predict SA potential. From this algorithm a time-based distribution of SA can be also compared to the workload distribution. Specifically, the C-130J releases the aircrew from manual station keeping tasks and presents a higher quantity and quality of information through the head's-up (HUD) and multifunction displays (MFD). **Hypothesis:** automated cockpits result in higher situation awareness than non-automated cockpits during formation airdrop.

3. How does automation affect aircrew workload during an airland mission?

The C-130J has fewer crewmembers (Pilot and Copilot only) than the C-130H, thus fewer personnel to share workload. Automation places a higher emphasis on programming computers via keyboards, but can also accomplish more checklist tasks with minimal or no human input. Automation can reduce task workload or eliminate tasks altogether. **Hypothesis:** automated cockpits result in a lower workload than non-automated cockpits during airland missions.

4. How does automation affect aircrew situation awareness during an airland mission?

The C-130J presents more data via the MFD, but it can also superimpose trend data through a flight path vector in the HUD, trend lines and various parameter gates. Conversely, the C-130H relies on analog gauges, some raw computer data (presented in numerical form), manually computed parameter gates, and simply looking out of the window. **Hypothesis:** automated cockpits result in higher situation awareness than non-automated cockpits during airland missions.

Methodology

The Army Research Lab (ARL) workload discrete event simulation tool, IMPRINT (Improved Performance Research Integration Tool), will be used to analytically study the effects of workload during sample tactical mission profiles. These mission profiles will simulate critical high-workload phases of flight over a tactical objective area (such as a drop zone or landing zone) and are unique to the airlift mission. Both aircraft will fly similar missions with tasks derived from checklists, regulations, and aircraft technical orders. This modeling provides quantitative data on experienced workload. Estimations can be made of available cognitive capacity that could be devoted towards situation awareness. Furthermore, the information gained by specific task accomplishment can also be figured into a situation awareness algorithm. These scenarios should demonstrate how workload and situation awareness are affected between comparable cockpit designs involving differing crew configurations.

Assumptions/Limitations

This research is limited to the tactical airlift mission using of the C-130. Due to the ability of the C-130 to perform multiple missions and the complexity of modeling each member of the cockpit crew, it is not practical to simulate many specialized mission sets or even variations on common missions. The discrete event simulation will assume that all crew members have similar level of abilities, expertise, competence and speed. Workload values and task times are taken primarily from the author's experience and from the experiences of other C-130 subject matter experts. These tasks derive from checklists, Air Force regulations, and experience with common tactical employment.

This also includes intra-cockpit and external communication as well as other common tasks that may not be explicitly codified. Finally, each simulation will have the same conditions and scenarios and will not feature any abnormal or unanticipated change. It may be impossible to achieve this direct comparison during an actual tactical mission.

While a wide body of historical and operational data on the C-130 exists, obtaining, publishing and analyzing that data is problematic. Air Force Safety Investigation Boards, which provide the most detailed information about C-130 mishaps is privileged information and cannot be released. This information includes Line Operation Safety Audits (LOSA) which reveals how aircrews handle mission workloads, threats and errors related to automation and crew compliments. Observational results may or may not clearly indicate which aircrew compliment performs best in each circumstance due to wide variations of avionics designs and accompanying procedures. What empirical data exists from drop scores, maintenance capable rates, and time over target may indicate an average that could show one aircraft to be superior to the other, but the data taken by itself could not explain if the cockpit-induced workload or resultant situation awareness was the cause of the difference in performance vice some other variable, such as weather or aircrew proficiency.

Implications

The results of the project demonstrate automation’s impact on tactical missions and crew situation awareness in fluid, unpredictable environments. Understanding the tradeoffs in workload, performance, and situation awareness when substituting manual crew input for automation may find benefits to automation in certain circumstances, but

adverse system behaviors in other circumstances that didn't exist in legacy, less automated systems.

Second-order effects of this research might extend to tactics developments and redesigned procedures stemming from a newfound understanding of task management understood tacitly by operational units. Impacts on capabilities can be weighed against available funding to drive cost-benefit analysis when evaluating acquisitions programs. Even unit manning and personnel management through the aircrew training pipeline are affected by the replacement of the human operator with automation.

Finally, technology's caveat emptor clause may not be explicitly written in a contract or in a flight manual, but nevertheless lurks in the logic circuits waiting for human operators to expose and, hopefully, mitigate safely through superior training, judgment, and airmanship.

II. Literature Review

Chapter Overview

This chapter will familiarize the reader with the man-machine interaction as it relates to cockpit design, automation, workload theory, situation awareness (SA), methods of measuring workload and SA, and discrete-event simulation. A basic understanding of cockpit design and the man-machine interface addresses some advances in technology and the information interface between the aircrew and the aircraft. The biggest advent in the avionics revolution in the last generation has been the increasing capabilities and reliance on automation, which come with their own set of risks and advantages. Cockpit design affects mental workload and situation awareness, which are examined in detail. Finally, a primer on discrete event simulation concludes the chapter.

Cockpit Design/Man-Machine Interface

An aircraft cockpit has a finite amount of space for controls and instrumentation. Cockpit layout is driven by mission, crew composition, and physical limitations. When the airplane was in its infancy, instrumentation was crude and the safe operation of aircraft was limited to clear weather, primarily during the day. The earliest aircraft (and some ultralights) relied so heavily on the pilot's visual perception that only a couple of instruments were included, and frequently were of the most basic variety (e.g. instead of a fuel gauge, a sight glass is used instead). Thus, when a pilot was unable to determine his position in space (altitude, attitude, speed, and course) visually due to night or adverse

weather, he could not fly his aircraft. In 1929, then-Lt. James Doolittle demonstrated the first “blind” instrument flight, including takeoff and landing, without any outside visual reference. Doolittle’s experiment was the first example of cockpit instrumentation able to provide a pilot with a three dimensional mental picture in real time (Edwards, 1988).

Basic cockpits, such as those found in early aircraft and basic general aviation only featured basic control and performance instruments. These were little more than a standard “six pack”: attitude, compass, altimeter, vertical velocity, airspeed, turn and slip, and a few engine instruments, fuel, and battery gauges. When aircraft grew more complex, they added more systems, navigation, performance, and mission-specific instruments. Naturally, a multi-engine aircraft requires identical sets of instrumentation for each engine. Extra radios and navigation equipment are innovated or added for enhanced mission capability. Each device, instrument, and control interface added to the cockpit consumes available space. Clearly, this physical design space is limited in fighter-type cockpits. Even large multi-crew aircraft have finite space for the multitude of instruments, even with the inclusion of side and overhead panels. This sometimes exceeds 400 distinct gauges and instruments for some commercial airliners (compared to 3 instruments on the original Wright Flyer) (Adams & Pew, 1990; Lovesey, 1995). Thus, it can easily grow beyond the capability of any one person to physically reach all of switches and controls, or even view the instrumentation.

As cockpits evolved, new “black boxes” were added: autopilot, radar, weapons systems, mission sensors, navigational aides, computers, etc. While many of the additions undeniably provided the aircrew with more information and solved specific problems, many were added in a piecemeal fashion as an upgrade to existing technology

and presented the aircrew with fragmented information. In some instances, these upgrades substituted existing equipment (e.g. upgrading and replacing a radar), but others were new additions to the cockpit. The legacy C-130H1 is a good example of post-production upgrades literally bolted onto existing instrument panels as aircraft capabilities evolved (Appendix A: Description of C-130 Aircraft). Additions, such as the Station Keeping Equipment (SKE) Plan Position Indicator (PPI), or "SKE Scope," mounted prominently on the pilots' instrument panel, obscure visibility through the center windscreen. Other equipment add-ons, from relatively low-tech aircraft armor, to Traffic Collision and Avoidance Systems (TCAS), to data-links, laptops, and moving map displays all consume some amount of physical design space and affect ergonomics as well as the operator's ability to view and manipulate the controls and displays included as a part of these design changes. Hence, a trend has been to completely redesign the cockpit holistically around state-of-the-art avionics versus making piecemeal changes (this captures the evolution of the C-130E/H to the C-130H3 to the C-130J).

Improvements in computing and information technology have led to cockpits that rely on round-dial "steam gauges" in a backup role, if at all. Instead modern cockpits are designed to use multifunction displays (MFD), commonly referred to as a "glass cockpit." By harnessing an integrated data bus, the avionics architecture can be controlled through a central processor or mission computer and data can be passed in any combination between sensors and displays. Instead of controlling components individually using different interfaces, a common design element in modern cockpits is a Flight Management System (FMS) that serves as a central input/output interface. Most,

if not all, data inputs could be made through a central (or pilot/copilot redundant) keyboards, while any variety of raw data can be displayed at the point of interface.

Glass cockpits allow more information (and more disparate forms of information) formatted on the same display space. Instead of requiring a display dedicated solely to an instrument, an MFD can creatively combine a multitude of information in the same space, while different data "layers" allow the operator to choose completely different data sets (i.e. a pilot can cycle from an attitude-centric display, to a system status display, to a navigation display, to a radar or moving map, etc.). New technologies, such as Heads-Up Display (HUD) allow for the display of information in the same field of view as the windscreen, thus allowing the pilot to look at a target (such as a runway) while referencing flight parameters (Haynes, 1998). These displays can use color coding, graphics and other symbology to enhance the quantity and quality of information.

In addition to HUDs and MFDs, other innovations of fully digital and glass cockpits include datalink, data-bus integration, fly-by-wire, enhanced terrain awareness, more capable autopilots, and improved ergonomic controls. Digital datalinks allow the passing of primarily text-based information that once could only be communicated via verbal radio transmissions. Thus, considerably more information can be relayed to the aircrew in a shorter time-span, with greater fidelity and detail, and without the same short-term memory and transcription limitations of voice-text. Aircrews crossing oceans relied on making position reports and receiving clearances by listening to scratchy and weather-distorted HF radios. With Selective Calling (SELCAL), air traffic control can "ping" the aircraft to listen to the HF radio, thus reducing the fatigue associated with

actively listening to that radio for hours. Further advances in technology allow aircrews to skip SELCAL and HF radio all-together and pass text messages through the FMS.

Related to data-sharing, modern digital cockpits feature data busses that seamlessly pass and fuse information from one component to another. Analog and transitional cockpits posses a limited capacity to share data between components. Putting the vast majority of the cockpit on an integrated data bus represents a revolutionary step in cockpit design and allows an individual aviator to call up and manipulate a wider variety of data.

The capability of the autopilot has evolved from a simple “wing-leveler” to the point where an autopilot coupled to autothrottles can autonomously fly an instrument approach and land in zero visibility. Display and ergonomic improvements put more data and control literally at the pilot’s fingertips. One key improvement in fighter aircraft lethality is Hands On Throttle-And-Stick (HOTAS): moving more control functionality over communications, systems, sensors, and weapons onto the flight controls and minimizing time spent searching for and reaching for switches in the cockpit.

In sum, designing a glass cockpit requires more careful considerations from the engineer. Simply adding automation or new display technologies is not a panacea for human-machine interaction, particularly if that interaction is too rigid (Secarea, 1990). While it is possible to present pilots with more data, information overload is a significant concern in modern cockpits (Hart & Sheridan, 1984; Secarea, 1990). Poorly designed and integrated interfaces increase the workload and time needed to synthesize information and open opportunities for larger errors and confusion (Secarea, 1990). Conversely, a smartly designed glass cockpit improvement can reduce workload by simplifying steps

required to manipulate instrumentation. Even the best designed cockpit displays and controls cannot overcome human performance limits (Hart, 1988). Provided that the operator does not have to flip through multiple layers to find this data or obscure the necessary information in a sea of data, modern displays provide more data in a richer format. Because glass cockpits rely much more on integrating display layers and inputs primarily through an Flight Management System (FMS) or keyboard, instrument manipulation that once consisted of twisting a dial or a couple of switches might now require paging through multiple display layers and a series of keyboard entries—all with an associated increase in workload and delay in time.

Automation

Automation is when a task is performed by a computer or machine instead of a human. Automation is prevalent in everyday life. While the term conjures thoughts of sophisticated computers, other everyday machines—ATMs, smoke detectors, elevators, automobile starter motors—are all examples of automation because they replace a function that a human once performed or could perform adequately (Parasuraman & Riley, 1997). As such, there exists a continuum of automation that provides the human operator with varying levels of control (Hart & Sheridan, 1984; Secarea, 1990). At the lowest end (no automation) is complete manual decision making and control by the human operator. Increasing levels of automation perform information management functions first, such as memory jogging or prompting, then serves as a decision and action assistant followed by full automation (Boys & Palko, 1988; Endsley M. R.,

1988b). Automation can exist as a decision aide along multiple levels defined in Table 1 and Table 2.

Table 1: Levels of Decision Automation(Hart & Sheridan, 1984)

1. Automated system suggests alternatives for operator to consider or ignore
2. Automated system lists alternatives from which operator must decide and execute manually
3. Automated system lists alternatives from which operator must decide, but system executes
4. Automated system makes decision and but informs operator, who can intervene before execution
5. Automated system makes decision and executes, only informing operator after the fact

Table 2: Levels of Human-Machine Interaction (Sheridan & Verplank, 1978)

Levels of Human-Machine Interaction
1. Human does all planning, scheduling, optimizing, etc. and turns task over to computer for deterministic execution
2. Computer provides options but human chooses between them, plans the operations, and then turns tasks over to computer for execution
3. Computer helps to determine options, and suggests one for use, which the human may or may not accept before turning task over to the computer for execution
4. Computer elects options and plans actions, which human may or may not approve; computer can reuse options suggested by human
5. Computer selects actions and carries it out if human approves
6. Computer selects options, plans, and actions; displays them in time for the human to intervene, and then carries them out in default if there is no human input
7. Computer does entire task then informs human of action
8. Computer does entire task and informs human upon request
9. Computer does entire task and informs human if it believes human needs to know
10. Computer performs entire task autonomously; human is ignored and must trust computer in all aspects of the decision-making

While there are ten levels of human-machine interaction, they can be classified in four main groups: information acquisition, information analysis, decision selection, and action implementation (Parasuraman, Sheridan, & Wickens, 2000). Information acquisition supports human sensing by controlling sensors and the registration of input

data. This could be a radar scan pattern, “lock on,” or automatic focusing. Information analysis filters raw data into something more contextual and therefore is useful for the human operator. In this case raw data is converted to symbology and certain performance characteristics are analyzed (e.g. a radar return has position, range, course and altitude data associated). Decision selection augments human decision abilities by presenting a desired choice to the human without taking that action. In many cockpits the flight director presents a desired heading and/or attitude correction to the pilot to correct back to the desired course and altitude. However it is the pilot’s choice to follow the flight director’s cue or choose another alternative. If the autopilot was coupled to the flight director, then the automation executes the flight director’s command, which implements the desired action. Of course a system, such as an aircraft, should change groups or adapt automation to the most appropriate level through the course of the mission (Parasuraman, Sheridan, & Wickens, 2000; Endsley M. R., 1996).

Just because something can be automated does not necessarily mean that it should (Wiener & Curry, 1980). While it may lead to legitimate cost savings or be inexpensive to automate a particular subsystem, whole system performance must be taken into consideration (Parasuraman, Sheridan, & Wickens, 2000). Automation can eliminate human tasks in some circumstances, but add new tasks or increase workload in others (Colombi, Miller, Schneider, McGrogan, Long, & Plaga, 2011). Automation can provide several advantages to the human operator. For instance, complex mathematical calculations, system monitoring and warnings (potentially leading to earlier detection of failures), fuel efficiency, consistent repetitions of mundane and routine tasks (i.e. cruise control or maintain a constant altitude) are good automation candidates (von

Tiesenhausen, 1982; Johnson, Bersheder, & Leifer, 1983). Information overload, especially dynamic information, can be filtered for relevance and urgency, or simply organized into more coherent form (Parasuraman, Sheridan, & Wickens, 2000). Precision afforded by automation could add new and more sophisticated/complex mission sets that either were not possible before, required more operators (i.e. a larger crew compliment), or was extremely taxing to the human operator(s) (National Research Council, 1982). An example of this is the MC-130H terrain following mission where a radar generated and computer calculated "cue" allows the aircrew to fly nap-of-the-earth missions accurately based on real-time aircraft performance with tighter tolerances and lower average altitudes than visual references alone (TO 1C-130(M)H-1, 2013).

In these situations, automation reduces operator workload, increases reliability, improves precision, improves safety by reducing human error, or a combination of these factors (Hart & Sheridan, 1984; Billings, 1991; Wiener E. L., 1985b). For instance, research into a synthetic vision upgrade to standard HUDs showed both improved performance (as measured by course and altitude deviations), better situation awareness, and a reduced incident of collision with terrain when used with approaches in instrument meteorological conditions (IMC) (AFRL, 2002). By reducing operator workload, fatigue accumulates more slowly, and the operator has more capacity to perform other, more critical tasks. Well-designed automation in modern, "intelligent" cockpits can serve as an assistant to the pilot just as if there was another crew member onboard (Secarea, 1990). In effect automation does not simply supplant human action, but can change human behavior (Parasuraman & Riley, 1997).

While automation easily replaces physical or manual control activities, the operator must monitor, supervise, and program these systems. This merely substitutes physical for mental workload, and despite removing skills, still requires a human operator to supervise (Endsley M. R., 1996). Furthermore, operators may potentially lose manual skills, systems knowledge, and even job satisfaction (Hart & Sheridan, 1984; Johnson, Bersheder, & Leifer, 1983). Automation itself lends another dimension of complexity to already complex endeavors. Operators must understand the automation's logic, functionality, and responsibilities, as well as its limits and operating parameters (Endsley M. R., 1996). Pilots have reported difficulties understanding what their aircraft automation is doing and why (Wiener E. L., 1989). This lack of appropriate communication has led to distrust, or at a minimum, confusion (Endsley M. R., 1996).

Dependency interactive automation elements may cause fixation to the neglect of other duties. For example, because HUD information can be so rich, yet in a narrow field of view, pilots can succumb to HUD dependency and must learn to look elsewhere outside (Haynes, 1998; Shinaberry, 2013; Kennedy, 2015). The precision afforded by an automated aircraft could become relied upon so heavily that a mission set is not able to be performed should that system fail or the mission set vary from the missions for which the automation was designed. For example, the C-17 depends on the Heads-Up Display (HUD) such that both pilot and copilot HUDs are required for short-field landings (Haynes, 1998; Rabbitt, 1998). Therefore the failure of either system can result in mission failure.

Continued use of automation can lead to human inactivity and complacency in the automated system (Hart & Sheridan, 1984). Inactivity may lead to inattention when the

operator should be supervising a highly-trusted system instead, cognitively (sometimes literally) putting the pilot to sleep (Secarea, 1990). Even more benign, pilots accustomed to more manual modes of flying feel psychologically distanced, or out-of-the-loop, from automated cockpits and processes being performed behind the veil of autonomy (Adams & Pew, 1990; Endsley M. R., 1996). A lack of vigilance can cause inattention due to a over-trust, a subtle, undetected error that seems reasonable, or simply because humans serve as poor passive monitors of automation (Billings, 1991; Parasuraman R. , 1987).

Complacency becomes pervasive if the operator views their role as passive with the operator becoming a passenger in his own aircraft (Hart & Sheridan, 1984). This is a function of operator trust (or over-trust) in automation and can lead to inattention or a lack of vigilance (Danaher, 1980; Parasuraman, Molloy, & Singh, 1993; Wiener E. L., 1985b). This lack of vigilance may be influenced by workload strategies employed by the operator to shift attention towards other tasks (Endsley M. R., 1996; Parasuraman, Mouloua, & Molloy, 1994). However, a lack of trust in automation may contribute to its non-usage or ignoring cues. For example, aircrews will ignore automatic alarms if they occur frequently enough to be considered erroneous or a nuisance (Billings, 1991; Wiener & Curry, 1980).

While automation itself may be inherently safe, it can contribute to hazardous attitudes: misuse (using it when it should not be used or improperly monitoring), disuse (not using available automation), or abuse (inappropriate use of automation) (Parasuraman, Sheridan, & Wickens, 2000). Automation, and the failure to monitor it properly, has been a factor in several accidents (Parasuraman & Riley, 1997; Endsley M. R., 1996). A highly automated Airbus A330-200, Air France 447, stalled and crashed

due to pilot error related to pitot tube icing. This created erroneous airspeed indications which promptly disconnected the autopilot and autothrottles while also changing automation logic and protections. As these changes were not communicated to the pilots, they became severely confused as to what information was valid and what logic mode the automation was operating in. Because of their high dependency on automation and comfort flying an aircraft designed to eliminate pilot-error with automatic protections, when these protections were removed, the pilots found themselves unable to recover with manual flying (BEA, 2012). Thus, in an attempt to eliminate pilot error via automation, the heavy reliance on such a system allowed basic manual flying skills, such as stall detection and recovery, to erode dangerously.

Fatal over-reliance and mode confusion are not limited to just this accident. A Boeing 777 crash at San Francisco International Airport, Asiana Flight 214, was due to the aircrew believing the auto-throttles were engaged when they were in a manual mode—a condition called mode confusion. The aircrew had trusted a system that was not engaged and failed to monitor a decay in airspeed due to the throttles being left in idle until a stall developed at very low altitude and just prior to the runway (NTSB, 2014). Another similar crash related to accidental autothrottle disengagement occurred to a US Air 737 (NTSB, 1990). Mode confusion led the aircrew of the airliner to climb at a constant vertical speed until it stalled at high altitude (NTSB, 1980; Wiener E. L., 1985a). Overconfidence in automation's reliability killed nearly everyone on a DC-9 when the aircraft attempted a no-flap takeoff. In this case, the crew had implicitly relied on a warning system that had failed and neglected to manually verify the position of the flaps (NTSB, 1988). Operator distrust (and disregard) in the significance of angle of attack

warnings led to an accelerated stall and total loss of a C-17 (Everhart, 2010). American Airlines 965, a Boeing 757, and Air Inter 148, an Airbus A320, crashed from controlled flight into terrain (CFIT) due to improper data entered into the autopilot (Hall, 1996; FAA). The inability of the crew to manually override the autopilot and mode confusion was causal to the *Exxon Valdez* oil spill (Wiener E. L., 1989).

While each incident was ultimately attributed to pilot error and is much more complex than described above, automation mode confusion, over-reliance, or distrust of information was causal in each incident. However, it would be unfair to label automated aircraft as inherently unsafe, since operator training is a significant factor in both accidents caused and prevented. Aircraft accident literature abounds with examples of incidents involving aircraft flown manually or with less automation available. Attempts to manually override automated safeguards, such as speed limits and stall recovery devices have resulted in accidents in both railroads and aviation—accidents automation was designed to prevent (Parasuraman & Riley, 1997). While automated systems are intended, among other things, to reduce pilot error, they cannot completely eliminate error (especially input error) and can induce new sources of error.

Poor design or usage of automation subjugates the operator to perform menial tasks to support the machine (Johnson, Bersheder, & Leifer, 1983; von Tiesenhausen, 1982). Even worse, automation may delay the response to unplanned, abnormal situations by either masking the cause-effect relationship, restricting feedback, or adding tasks required to take action (Hart & Sheridan, 1984; Endsley M. R., 1996; Norman D. A., 1989; Billings, 1991). Automation or systems failures increase pilot stress and workload greater than similar failures in less automated systems (Hart & Sheridan, 1984).

This can be due to the amount of data or control lost during an automation malfunction, the quantity of tasks or button-pushing required to remedy the situation, or the operator's dependence on the automated system. During normal operations, automation can become the distracting object of attention instead of an in-flight assistant due to poor interface design, programming or operating difficulty, lag time, software bugs or user error (Adams & Pew, 1990). Even in normal operation, a majority of pilots felt that automation increased workload due to manipulation and reprogramming requirements (Wiener E. L., 1985a; 1989; Parasuraman & Riley, 1997; 2000).

To effectively use automation, operators should consider the appropriate level of automation for the situation at hand. This may entail selecting a higher level of automation to deal with a more urgent task priority or deselecting and performing a task manually when fixing automation imposes an unacceptable time penalty. System designers should allow for the operator to override automation, where appropriate, and incorporate adaptive levels of automation for the operator to choose from. Ideal candidates for automation include:

- Low level, repetitive, and menial tasks
- Tasks that require long attention spans (i.e. systems and sensor monitoring)
- Data fusion from disparate sensors into a combined display/overlay
- Intense or recurring computing tasks
- Tasks requiring little mental effort yet provide immediate feedback
- Basic decision making within a well defined, constrained, set of rules.

Tasks that involved abstract though, complex decision making, critical thinking, planning, and problem solving are better left to the human operator (Hart & Sheridan, 1984; von Tiesenhausen, 1982; Johnson, Bersheder, & Leifer, 1983). This potentially creates a dilemma where those tasks that invoke the least mental workload are easily automated (simple transit and navigation), while those tasks that impose the highest mental workload (complex planning, emergencies, communications) or are hard, expensive, or impossible to automate are left to the human (Colombi, Miller, Schneider, McGrogan, Long, & Plaga, 2011; Parasuraman, Sheridan, & Wickens, 2000). Ideally, automation should free operators from the boring, mundane, and time-consuming tasks, enabling them to perform more critical tasks (Hart & Sheridan, 1984; National Research Council, 1982).

Proper automation design and control should result in an acceptable workload such that the operator is engaged and involved with flight tasks. The aircrew must be free to perform necessary planning and other high-level functions as appropriate, yet flexible to respond to time-critical tasks. System engineer's goals should be to reduce system complexity to enhance operator performance and use automation where it can be most beneficial (or use automation most appropriately) while preventing information overload (Mitchell, 2000).

Pilots are concerned that automatic systems can implement decisions without their consent (Secarea, 1990). From 2010 to 2014, there were 53 aircrew initiated safety reports of automation overriding the crew (NASA, 2014). In a survey of airline pilots, fully automatic control without override ability was universally detested, while most pilots preferred either a management-by-consent (similar to Sheridan & Verplank's levels

4 and 5 of automation) or management-by exception (level 6) form of automation, depending on the situation (Olson & Sarter, 1998). Achieving the proper level of automation in the cockpit is a function of cockpit design, Crew Resource Management (CRM) training (not described in this thesis), and training tailored to that specific aircraft.

Workload Theory

Aircrew workload, specifically the pilot's workload, has been a design concern in complex aircraft for years. As automation technology matured in the 1980s, the relationship between automation management and operator workload began to be studied in earnest. Mental workload itself is a complex phenomenon, a consistent definition of which has not reached consensus (Hart & Sheridan, 1984; Secarea, 1990; Kantowitz & Casper, 1988; Mitchell, 2000). Mental workload can be expressed in several different ways. It may be partially characterized as "time pressure" or comparing the actual time available against the perceived time available (Sheridan & Stassen, 1979). It could be a task-dependent measure of cognitive bandwidth (Secarea, 1990; Hart & Sheridan, 1984). It can also be defined as a function of time load, mental effort, and psychological stress (Reid, Potter, & Bressler, 1989; Reid & Nygren, 1988).

For the purpose of this thesis, mental workload is the relationship between an operator's mental capacity and the required attentional resources needed to perform a task (Hart & Staveland, 1988). Workload should not be confused with *task load*, which is an expression of the quantity of tasks performed in a finite period of time (thus incorporates an element of time pressure). *Task demand* reflects difficulty and is the level of effort required by the task. Therefore, workload is a combination of task load and task demand.

An operator could have a low task demand yet a high task load if they are performing many simple tasks. Conversely, the operator may experience the same workload if it involves high task demand yet low task load (few tasks, but they require a large amount of cognitive resources). Even for a given task, the experienced workload can vary between operators since each may have different capacities. Capacity is a function of the individual traits, environment, fatigue, operator experience, level of training, proficiency, workload strategy, and stress (Hart & Sheridan, 1984; Curry, Jex, Levison, & Stassen, 1979; Childress, Hart, & Bortolussi, 1982). Stress is a function of the confusion, frustration and anxiety associated with the task (Reid, Potter, & Bressler, 1989). In addition to psychological stressors, physiological stress—G's, turbulence, motion sickness, temperature, and equipment-induced stress—affect aircrew, particularly in tactical or combat scenarios (McDaniel, 1996).

Human Performance and Workload

There is no simple relationship between human performance and workload (Sheridan & Stassen, 1979). The concept of arousal affecting performance was first studied by introducing rats to electrical shocks to facilitate simple discrimination tasks. Thus the rats learned faster when stress was increased, up until a point (Yerkes & Dodson, 1908). Later research theorized human performance is a function of arousal, with increasing arousal leading to increased cognitive performance (Hebb, 1955). Performance can be low in a low workload situations (a condition called *underload*) if the operator is not sufficiently aroused, committed, or under-resourced the task. Conversely, performance can be maintained at a high (or increasing) level as arousal (i.e. workload) increases from low to high (Figure 1). Generally, performance increases as more

operator resources (i.e. effort) are invested in the task until the point where no further increase is possible. Thus, capacity can be said to increase as arousal increases in a function attributed as the Hebb-Yerkes-Dodson Law (Kahneman, 1973). Workload, urgency, significance, and enjoyment all affect arousal level. Even a relatively low-demand task sparks arousal if successful completion becomes a matter of life-and-death (McDaniel, 1996).

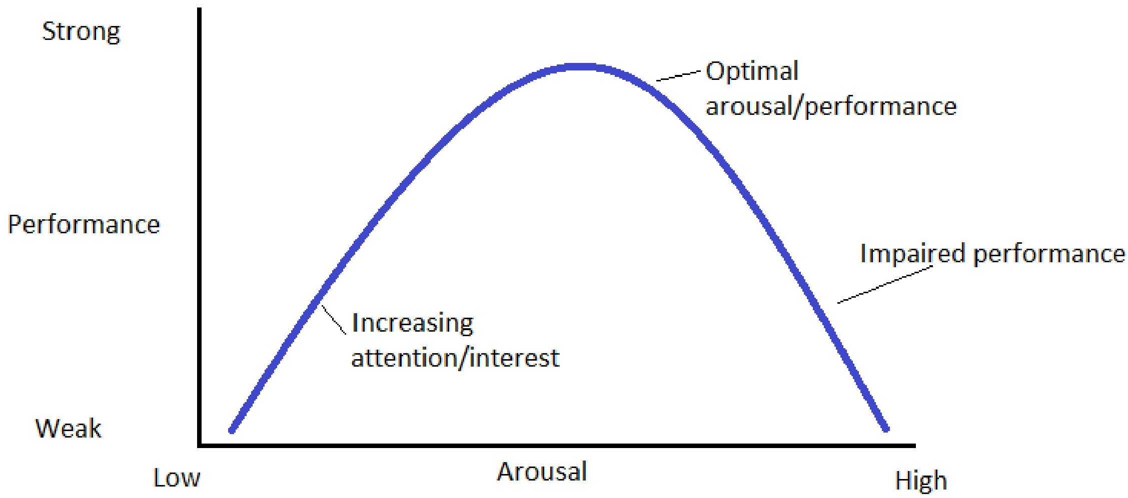

Figure 1: Performance-Arousal Function (Diamond, Campbell, Park, Halonen, & Zoladz, 2007; Hebb, 1955)

Overload is the condition when the operator's workload exceeds mental resource capacity. When the operator becomes overloaded, performance deteriorates rapidly (Kahneman, 1973; Hart & Sheridan, 1984). However, it is not possible to define an overload "redline" that is true for all cases and conditions because operator capacity covaries with both the task at hand and the operator's skillset (Wickens C. D., 1984; 2002). This phenomenon may be described as the performance-resource function (Figure 2). Below this point, the performance curve may be said to be resource limited since

more resources results in improved performance. From that point until 100% resources are committed to the task, it is said to be data-limited because performance cannot increase no matter how hard one tries (Wickens C. D., 1984; 2002; Norman & Bobrow, 1975). Conversely, a low difficulty task simply cannot demand a high level of effort beyond what is required for a zero-error rate (Kahneman, 1973). The concept of *underload*, where an operator is not sufficiently aroused can lead to boredom or complacency. Complacency can lead to task failure, even in low task demand, when an operator views that task in low regard and invests insufficient or no resources at all. For instance, an experienced tactical pilot can become complacent and fly the aircraft into the ground (McDaniel, 1996).

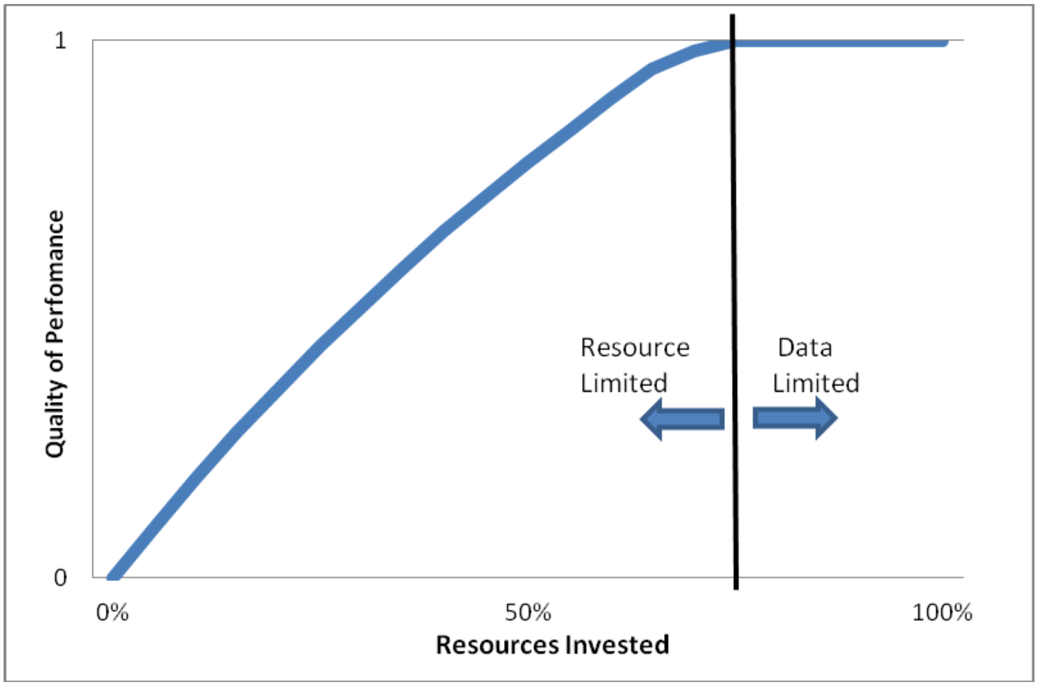

Figure 2: Performance-Resource Function (Wickens C. D., 1984)

Capacity and Resource Theory

Workload could be said to be proportional to task demands imposed on an operator's capacity, inferring that an increase in operator capacity (i.e. training, experience, etc.) can have similar effects as reducing task load (Wickens C. D., 2002; Rolfe, 1971). A given operator has a limited capacity to devote mental effort, or attention, to any given task and often attempts to perform smaller tasks in parallel (Wickens C. D., 1984; 2002). *Time-sharing*, commonly known as multitasking, is the ability to perform multiple tasks in parallel. The proverbial "walking while chewing gum" illustrates multitasking of two largely physical tasks that demand little mental workload. This example might be considered an example of efficient time sharing because both tasks can be performed in parallel just as well as in isolation (Wickens C. D., 1984).

Conversely, two higher workload tasks, such as patting ones head and rubbing the stomach simultaneously, may demand too many mental resources to be performed concurrently and the tasks are disrupted. Because each of these examples involves tasks that occupy similar mental "channels," they share the same resources and in the second example, a "bottleneck" occurs. Both rubbing one's head and patting one's stomach involve conscious cognitive effort to dictate motor functions, whereas one may argue that walking is an almost subconscious activity.

Attention is one key component of available mental capacity. Logically, an operator cannot perform any mental work towards a task if he cannot pay any attention to it. Since humans have finite attentional resources, and finite capacities for work, they prioritize tasks and may elect to devote fewer resources to obtain acceptable performance. Because attention is active, it requires effort and therefore induces work (Kahneman, 1973). This finite limitation of attention leads to a bottleneck where the operator cannot process all of the information available (Kahneman, 1973). Just like a human has focal and peripheral vision, a similar analogy can be drawn when the same human filters attentional demands, such as listening to a conversation with a television in the background. This person can choose to listen to one intently, while still hearing the other in the background. Depending on the degree of divided attention, this listener can notice any number of attributes or cues from the background conversation but will have difficulty discarding certain irrelevant cues (e.g. it's nearly impossible to observe the shape of an object without noticing its color) (Kahneman, 1973).

In capacity theory, the operator has a finite capacity or "pool" of given resources to allocate to primary and secondary tasks (Wickens C. D., 1984; Knowles, 1963;

Kahneman, 1973). Unitary or single-resource theory assumes that only one pool of resources exist, which is available to all mental processes equally (Wickens C. D., 1984). The workload imposed by the primary task could be measured as the inverse relationship of secondary task performance, thus showing an attention or resource bottleneck (Knowles, 1963). However, attention connotes awareness, which is not related to specific task performance (Wickens C. D., 2002). If the secondary task imposes relatively low demand, then impact on primary task performance may not be measurable. Thus, as multiple tasks are being performed concurrently, the operator's performance is dictated by the amount of resources demanded beyond the data-limited regime of the performance-resource function (Wickens C. D., 1984). However there are certain limitations towards time-sharing of even simple tasks: one cannot look in two places in separate fields of view at once, and the act of time-sharing itself can pull away mental resources, such as texting and driving (Wickens C. D., 1984; 2002). However, this constraint does not exist (to the same extent) if listening to the radio and driving,

Single-resource theory breaks down when trying to explain difficulty insensitivity: that is, the performance of a difficult primary task is not adversely affected by the secondary task. If one or both tasks have sufficient data-limited regions on the performance-resource function, then single resource theory could explain this insensitivity (Wickens C. D., 1984). But if both tasks are thought to be more resource limited, and are performed perfectly in parallel, it may be because there is no structural interference between the two tasks. Multiple-resource theory maintains that there are multiple separate resource pools that can be allocated as necessary (Wickens C. D., 2002). Perfect multitasking occurs when two tasks do not use overlapping resources.

Similarly, two difficult tasks can impose heavy workload without a degradation of performance, provided that separate resource pools are required (Wickens C. D., 1984). However, a resource demanding task combined with memory-demanding cognitive process can create performance degrading interference (Wickens C. D., 2002).

This multiple-resource theory posits that multiple dimensions exist to define a capacity reservoir: stages of processing, perceptual codes, modalities of input, and modalities of response (Wickens C. D., 1984). Processing stages compares a central processing function versus cognitive response. Perception exists in both verbal and spatial domains; input modalities can be either visual or auditory, and response modalities can be manual or vocal (Wickens C. D., 1984). Parallel processes are still possible within the same channels that still use separate, non-interfering resources. An example of this is using focal and ambient (or peripheral) vision to accomplish two separate tasks (Wickens C. D., 2002). Thus a task may demand resources in varying degrees from different (and multiple) reservoirs. Human performance can still be explained by applying the performance-resource function to the capacity in each reservoir. Considerable research has been conducted regarding the complex interaction of each dimension and channel on the effects of operator performance and task efficiency (Wickens C. D., 2002; Vidulich, 1988; Martin G. , 1989; Martin, Wogalter, & Forland, 1988; Sarno & Wickens, 1995; Goodman, Tuerina, Bents, & Wherewille, 1999; Polson & A, 1988; Paivio, 1971; McLeod, 1977)(Wickens C. D., 1980; Tsang & Wickens, 1988; Wickens & Liu, 1988).

In a system-of-systems analysis of multiple remotely piloted aircraft control, multiple simultaneous primary responsibilities (i.e. piloting demands) drove a naturally

higher workload, but secondary tasks (namely, radio communication) drove “extreme spikes” in mental workload. When the primary task is unexpected and urgent, such as an emergency or dynamic, unplanned situation, the workload (with associated attention resources) becomes so high that secondary tasks are neglected (Colombi, Miller, Schneider, McGrogan, Long, & Plaga, 2011).

From an engineering standpoint, multiple-resource theory describes operator performance, which tasks can be performed in parallel, the amount of interference between multiple tasks, and how increasing difficulty in one task affects the performance of other tasks (Wickens C. D., 2002; Little, et al., 1993). Thus, in time-constrained, task-intensive environments, such as the one faced by any aircrew, multiple-resource theory can predict the effects of different modalities (i.e. effects of receiving information via voice or auditory means), or even the value added of multitasking or sequencing when evaluating procedures.

Expertise

An expert might experience lower workload than a novice for the same given task because the expert perceives how that task interacts with other tasks (Secarea, 1990; Hart & Sheridan, 1984). For instance, the expert is expected to have a better grasp of how an individual task fits into the bigger picture (National Research Council, 1982). However, the experts’ advantage of pattern recognition decreases as the value of information becomes less meaningful. One would expect an expert to develop efficient workload strategies and more ‘automatic’ motor responses by virtue of his/her experience. However, the introduction of a surprise or novel situation or dilemma requires a surge of attention and greater mental processing resources (Kahneman, 1973). Failures,

abnormalities, and surprises will affect the expert differently than the novice, and mistakes made by the expert operator are likely to be recognized and corrected in a timely manner with an associated lower level of workload (Hart & Sheridan, 1984).

Workload Strategies

Pilots frequently find themselves responding to multiple, simultaneous demands with frequent and unpredictable interruptions, which forces them to adapt various strategies to keep workload at a manageable level. They respond to some (multitasking where appropriate), defer and delay others and interleave the rest (Loukopoulos, Dismukes, & Barshi, 2009). Before reaching overload operators can simply increase the level of effort to meet increased workload with consistent performance (Hart & Sheridan, 1984). The operator could chose to reduce the required level of performance or shed certain tasks in order to keep the workload level manageable (Hart & Sheridan, 1984). Pilots have been shown to trade speed for accuracy where required performance allowed, rather than optimize performance, which also reduces the utility of expertise (Higgins & Chignell, 1988; Secarea, 1990).

One of the most common forms of workload management strategies the operators believe they use to cope with high-workload situations is *multitasking*. However, true multi-tasking (i.e. perfect time-sharing) as described in multiple-resource theory is often confused for other workload strategies (Wickens C. D., 2002). *Interleaving* is the process of temporarily interrupting Task A to perform part of Task B then returning to Task A and repeating the process (Alion Science, 2013). Some tasks may intentionally be omitted, called *task shedding. Delegating* is task shedding from one operator and assigning the task to a different operator (Brockman, 2010). *Adaptive attack* is similar to

interleaving, but instead of Tasks A and B performing concurrently, the operator prioritizes one task and defers the other until resources are available. Both task shedding and adaptive attack are common strategies for unplanned, dynamic events that are high priority. On the other hand, interleaving may be used when checklists or procedures are run concurrently, or when giving a brief while executing a checklist (Loukopoulos, Dismukes, & Barshi, 2009; Adams & Pew, 1990).

Workload strategies are not without their risks and aviation safety literature abounds with accident reports and anecdotes of mistakes caused by missed procedures and improperly managed workload. NASA reported more than 50 incidents of attempted no-flap takeoffs in the decade preceding 2009--an error that has resulted in numerous fatal accidents and is often caused by omitting checklist steps in the often distracting and hectic before-takeoff phase of flight (Loukopoulos, Dismukes, & Barshi, 2009; NASA, 2014; Adams & Pew, 1990). While workload may be neatly ordered when designing a procedure, random real-world noise, such as radio traffic or the requirement to navigate a complex set of taxi instructions often interrupts this flow (Loukopoulos, Dismukes, & Barshi, 2009). Distractions and demands simply do not allow for the neat and orderly flow of tasks to the operator (Adams & Pew, 1990). This forces some type of workload strategy and can potentially compromise operator performance. As a result of compromised performance, task simplification is recommended to reduce workload and increase performance (Secarea, 1990).

Pilots typically believe that they are good at multi-tasking, yet oftentimes this fact is hidden in that most tasks performed in parallel are highly rehearsed, thus performed almost automatically. The unpredictability forces pilots to interleave tasks in an ad hoc

and creative manner (Loukopoulos, Dismukes, & Barshi, 2009). Although the vast majority of these impromptu workload strategies result in acceptable task completion, the randomness of the interruption and ad hoc response strategy can lead to serious omissions and deviations from procedures, especially when habit patterns are broken (Loukopoulos, Dismukes, & Barshi, 2009). Hence, checklists (particularly challenge and response), automated monitoring systems (such as gear and flap warning horns) and informal processes serve to catch these inadvertent omissions.

Workload Measurement

While physical workload can be judged by evaluating physical movements, mental workload, in particular, is difficult to measure. It is difficult to define workload during monitoring tasks unless there is any overt response (Hart & Sheridan, 1984). In aviation, particularly tactical and combat missions, significant effort is devoted to sensory intake and processing (McCracken & Aldrich, 1984). This difficulty compounds when operators are transitioning from mundane monitoring to a complex and urgent emergency situation management (Hart & Sheridan, 1984). Monitoring an automated system in which the operator has a high level of trust may have a low perceived workload and not as easy to observe, whereas a system that the operator does not trust will result in a very conscious, therefore reportable, level of mental workload. Indeed, an operator is more inclined to use automation when trust is high, and leave even that system engaged if it malfunctions. Thus, the operator may be forced to trust automation as a workload management strategy when under stress or to free up resources for complex problem solving tasks (Parasuraman & Riley, 1997; Parasuraman, Sheridan, & Wickens, 2000). Conversely, an operator who has low trust in automation will be less likely to use it and

quicker to disconnect it when something abnormal happens (Parasuraman, Sheridan, & Wickens, 2000).

Operators will sometimes seek to fill unused capacity. While a task may not require overt mental work, the human operator may find mental activities to occupy him/her. These activities may be indirectly related to the task at hand (i.e. planning), developing situation awareness, or may be daydreams or musings (Hart & Sheridan, 1984). Mental processing workload related to situation awareness is non-trivial, yet not explicitly linked to any given task. This level of distraction cannot be objectively measured and is far too complex to be predicted, yet it occupies part of the operator's finite mental capacity (Hart & Sheridan, 1984).

Workload can be measured empirically or analytically through both subjective and objective means (Rusnock, Borghetti, & McQuaid, 2015). Empirically, workload is adjudicated with subjective evaluations, surveys, and/or measuring some kind of physiological response (i.e. heart rate, eye movement, electrical brain activity, etc). Analytical and deterministic methods can begin with the design phase and calculate expected workload values from a task network analysis. Analytical workload measurement techniques are predictive in nature, therefore offer a better evaluation of workload for systems still in the conceptual stage (Mitchell, 2000). Analytical methods aim to calculate the cumulative workload imposed by a series of tasks. These are frequently performed as computer simulations, such as VACP, or direct performance measurements (either physiological or some physical parameter). However, if there is no established benchmark of tasks in a controlled environment, then there can be no objective measure of workload to compare against (Hart & Sheridan, 1984). Most

common forms of measuring workload are subjective evaluations performed by the operator after an experiment is run, usually in the form of a survey or questionnaire. Subjective workload assessments may easily capture the essence of mental workload, especially when the effects of many different contributing factors may be poorly understood (Hart & Staveland, 1988). While subjective assessments lend themselves easily to both researchers and subjects alike, they are not without problems. Subjective methods rely heavily on judgment, which is influenced by heuristics and biases. If a task was performed multiple times during the experiment, the subject may only be able accurately recall the most challenging or latest iteration of that task. Information fidelity erodes as time elapses such that tasks performed early in the experiment or a questionnaire conducted well after the task occurred rely more on the recall ability of the test subject (Hart & Staveland, 1988).

Biases aside, subjective methods must establish a degree of consistency in workload ratings. Thus, they typically involve relative, linguistic measures such as “low” and “high” and avoid quantifying workload values. Since task variables covary with the test subjects involved, subjective workload assessments can produce different values of experienced workload (Hauser, Childress, & Hart, 1982; Hart & Staveland, 1988). For a given task, variance is also expected as a result of different task weights reflected from the evaluator’s biases (Hart & Sheridan, 1984). Questionnaire results may only reveal overt responses and conscious mental effort while masking subconscious and background processes (Hart & Sheridan, 1984). Most issues with consistencies and biases can be mitigated with a large sample size of test subjects. The three most common methods of

subjective workload ratings are: the Subjective Workload Analysis Tool (SWAT), the Cooper-Harper Index, and NASA's Task Load Index (TLX).

Subjective Workload Analysis Tool (SWAT)

Subjective Workload Assessment Technique (SWAT) measures mental workload only and assumes that the experimenter will use another technique to measure physical workload for any significant tasks, if applicable. (Reid, Potter, & Bressler, 1989) Either during or immediately after an experiment is run (or both) the operator rates mental workload on the pre-briefed set of scales (Reid, Potter, & Bressler, 1989). Based on the operator rating of workload, the investigator weighs each component (time load, mental effort, psychological stress) and computes a final SWAT value based on the scale algorithm. The speed or accuracy of task completion theoretically indicates workload. However, this empirical method may not account for workload management strategies, information quality, or the relationships between primary and secondary tasks (Mitchell, 2000). Thus, an operator evaluation of perceived workload does not reliably predict performance (Tsang & V, 1996).

Cooper-Harper scale

The standard scale for evaluating aircraft handling qualities has been the Cooper-Harper scale. This scale originally seeks to standardize aircraft flyability by defining "handling qualities" as more than simple aerodynamic stability and control by considering cockpit design (visibility, displays, and control), task performance, and implicit factors, such as stress and environment (Cooper & Harper, 1969). By incorporating miscellaneous cockpit tasks with basic aircraft control qualities, this scale correlates perceived workload with performance from the pilot's point of view. A

qualitative scale such as this may be desirable when applying real-world stress and environmental pressures, auxiliary tasks, etc., cannot neatly be measured experimentally. Cooper and Harper concluded at the time that it was impossible to measure all aspects of pilot performance and that there needed to be operator feedback to illustrate those areas that could not be measured explicitly, thus a pilot-rating scale was the only method to show workload at the man-machine interface (Cooper & Harper, 1969). The revised Cooper-Harper scale is a numerical rating scale designed to be used in conjunction with a written evaluation to identify and amplify design shortcomings. Figure 3 shows the original Cooper-Harper rating scale. The scale asks the pilot to make up to three decisions regarding performance that Pilot performance (or compensation) describes a level of physical workload. The Bedford scale is another aircraft handling/workload scale similar to the Cooper-Harper.

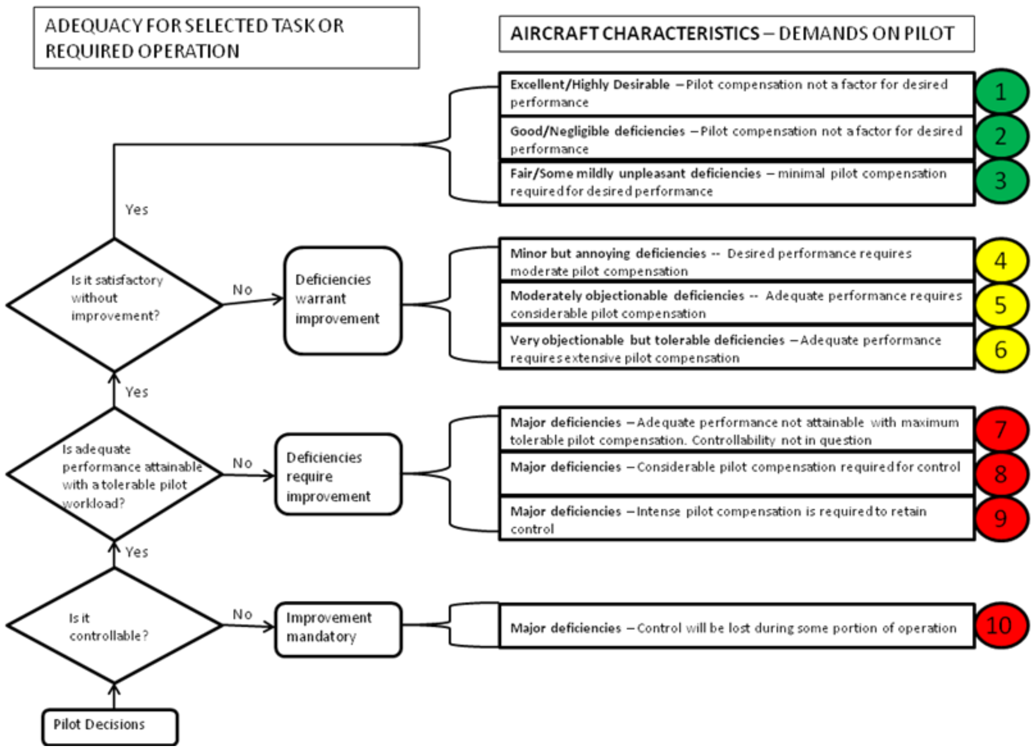

Figure 3: Handling Qualities Rating Scale(Cooper & Harper, 1969)

<u>NASA Task Load Index (NASA-TLX)</u>

The NASA-developed Task Load Index (TLX) is a popular subjective workload evaluation technique. NASA-TLX computes an overall workload score based on weighted averages of six scales: metal demand, physical demand, temporal demand, performance, effort, and frustration (NASA, 2015). TLX theory assumes that task demands (mental, physical, and temporal) are multi-dimensional, may covary, and contain some objective measure of magnitude (i.e. difficulty) and importance (Hart & Staveland, 1988). These demands are perceived by the operator, who also applies psychological variables to yield emotional, cognitive, and physical responses which then can be evaluated (Hart & Staveland, 1988). The amount of covariance is situation

dependent, and TLX seeks to identify task demands and the non-task factors and stressors that are implicit to the situation.

In practice, after an experiment is run, each operator/test subject is asked a question relevant to each task according to the subscale. The operator responds by marking appropriately along each scale, which appear arbitrary and linguistically descriptive. The experimenter applies a numerical value based on the operator's rating, which is added together to generate a weighted workload score and thus an overall workload rating for that task (Hart & Staveland, 1988).

Physiological Methods

To maintain performance as workload increases, the operator must increase effort. The human body has a measurable physiological reaction to workload and stress. Several methods of measuring physiological reactions are:

- Heart rate activity such as heart rate variability from Electrocardiograms (ECG or EKG) (Jorna, 1991; Watson, 2001; Wilson, 1991; 2001; Siegel & Keller, 1992)
- Respiration rate (Wilson, 1991)
- Eye movement (Siegel & Keller, 1992; Wilson, 1991; 2001; Schnell, Macuda, Poolman, & Keller, 2006)
- Brain activity, such as those measured from Electroencephalograph (EEG), Event-related potential (ERP), and Positron emissions tomography (PET) (Wilson, 1991; 2001; Schnell, Macuda, Poolman, & Keller, 2006)

While physiological measurements can be useful for determining areas of high workload, they are empirical in nature, therefore they cannot serve as useful predictors to engineers before a prototype is constructed (Mitchell, 2000). Also, if an operator employs effective workload strategies in an effort to balance or level experienced

workload, then high workload peaks may not manifest themselves significantly in a physiologically measurable way (Kramer A. F., 1991). Their physiological effects may lag behind the actual task, thus making it difficult to correlate imposed workload for any specific task or time. However, when combined with questionnaires and known baselines, physiological measurements can be used to correlate subjective workload methods (Svensson, Angelborg-Thanderz, & Wilson, 1999).

Pilot Performance Measurements

Pilot performance can be measured objectively by recording deviations from any number of in-flight parameters. Aircrews are trained to recognized decreased performance shown in late verbal responses, erratic or illogical control movements, delayed or ignored cues and prompts (McDaniel, 1996). The degree to which a pilot exceeds a given flight parameter (i.e. glideslope, altitude, heading, etc.) can demonstrate how performance suffers from high workload (McDaniel, 1996). However, by its nature, this method solely measures performance, which as described earlier, may only correlate to periods of excessively high workload or low operator motivation. It is best to use performance measurements in conjunction with other workload assessment techniques.

Visual, Auditory, Cognitive, Psychomotor (VACP) Analysis

A VACP analysis can account for the multiple-resource theory concept of channels or components of workload. These channels--visual, auditory, cognitive and psychomotor--were scaled and quantified first by McCracken and Aldrich (1984) to predicatively quantify task workload for a proposed light scout/attack helicopter (Table 3). Each channel was divided into an ordinal scale and assigned various descriptors

according to increasing level of task demand. Complex tasks involving multiple channels simply add the individual channel values together for a total workload.

Table 3: VACP(McCracken & Aldrich, 1984)

Scale Values	Descriptors
	Visual
0.0	No activity
1.0	Monitor, scan, survey
2.0	Detect movement, change in size/brightness
3.0	Trace, follow, track
4.0	Align, aim, orient on
5.0	Discriminate symbols, numbers, words
6.0	Discriminate based on multiple aspects
7.0	Read, decipher text, decode
	Auditory
0.0	No activity
1.0	Detect occurrence of sound, tone, etc.
2.0	Detect change in amplitude, pulse rate, pitch
3.0	Comprehend semantic content of message
4.0	Discriminate sounds on the basis of signal pattern
	Cognitive
0.0	No activity
1.0	Automatic (stimulus-response)
2.0	Sign/signal recognition
3.0	Alternative selection
4.0	Encoding/decoding, recall
5.0	Formulation of plans (projecting action sequence, etc)
6.0	Evaluation (considering several aspects)
7.0	Estimation, calculation, conversion
	Psychomotor
0.0	No activity
1.0	Discrete actuation (button, toggle, trigger)
2.0	Discrete adjustive (variable dial, etc)
3.0	Speech using prescribed format
4.0	Continuous adjustive (fight controls, sensor controls, etc)
5.0	Manipulative (handling objects, maps, etc)
6.0	Symbolic production (writing)
7.0	Serial discrete manipulation (keyboard entries)

This initial VACP model was modified by Bierbaum, et al (1989) to adjust scale the ordinal scale into a ratio scale. The modified VACP scale (Table 4) offers more refined,

and in some cases, reordered workload values and descriptors and includes employment of night vision goggles (NVGs)(Bierbaum, Szabo, & Aldrich, 1989).

Table 4: Modified VACP Scale(Bierbaum, Szabo, & Aldrich, 1989)

Scale Values	Descriptors
	Visual
0.0	No activity
1.0	Visually Register/Detect occurrence of image
3.7	Discriminate symbols, numbers, words
4.0	Visually inspect/check (discrete inspection/static condition)
5.0	Visually locate/align (selective orientation)
5.4	Visually track/follow
5.9	Read (symbol)
7.0	Visually scan/search/monitor (continuous/serial inspection)
	Auditory
0.0	No activity
1.0	Detect occurrence of sound
2.0	Orient to sound (general orientation/attention)
4.2	Orient to sound (selective orientation/attention)
4.3	Verify auditory feedback (detect occurrence of anticipated sound)
4.9	Comprehend semantic content of message
6.6	Detect change in amplitude, pulse rate, pitch
7.0	Discriminate sounds on the basis of signal pattern
	Cognitive
0.0	No activity
1.0	Automatic (simple association)
1.2	Alternative selection
3.7	Sign/signal recognition
4.6	Evaluation (consider single aspect)
5.3	Encoding/decoding, recall
6.8	Evaluation (considering several aspects)
7.0	Estimation, calculation, conversion
	Psychomotor
0.0	No activity
1.0	Speech using prescribed format
2.2	Discrete actuation (button, toggle, trigger)
2.6	Continuous adjustive (fight controls, sensor controls, etc)
4.6	Manipulative (handling objects, maps, etc)
5.8	Discrete adjustive (variable dial, etc)
6.5	Symbolic production (writing)
7.0	Serial discrete manipulation (keyboard entries)

A predictive workload analysis evaluates a function of tasks up to an entire mission by constructing a task analysis, then applying time values to task duration and

sequencing to develop a task flow. Then VACP workload values are added to each task. The resultant workload analysis documents total composite workload over time.

Situation Awareness

The ability to conceive of the aircraft's whereabouts, status, weather, fuel state, terrain, and, in combat, enemy disposition is critical to effective aircraft operation. In critical phases of flight, poor weather, or in the face of systems malfunctions or can mean the difference between mission success and failure or even survivability. Operator performance in complex or dynamic environments is often a function of situation awareness (SA) (Secarea, 1990). Aircrews spend considerable portions of time and effort developing and maintaining SA, especially in evolving environments (Endsley M. R., 1999). Indeed the military has had a keen interest in SA in the cockpit dating back to World War I and especially more so in the information age of the late 20th century (Endsley M. R., 1995a; Press, 1986; 57th Figther Wing, 1986). In tactical situations, this includes knowledge about the locations, actions, and capabilities of both friendly and enemy forces (Endsley M. R., 1988a; 1999). SA is considered so important that it is considered a 'critical' grading area for flight evaluations (check rides) for Air Force C-130 crews (AFI 11-2C-130, Vol. 2, 2014). A demonstrated failure to maintain SA would result in a failure of the check ride and loss of aircrew qualification (AFI 11-2C-130, Vol. 2, 2014). A leading cause of military and 88% of commercial aviation accidents have been attributed to poor SA (Endsley M. R., 1994; Hartel, Smith, & Prince, 1991).

Situation awareness is the knowledge of environmental factors that influence decisions and depends on the operator's internal perceptual model of the world (Klein,

Calderwood, & Clinton-Cirocco, 1986). SA is the operator's perception (or mental model) of elements in the environment around him within a volume of space and time, the comprehension of their meaning, and the projection of their status into the future (Endsley M. R., 1988a; 1999). Situation awareness drives decision making based on the operator's mental model of the environment. Situation awareness, while independent from decision making, forms a basis for it (Endsley M. R., 1995a; 1995b). The performance of a combat pilot is highly related to the fusion of decision-making and SA (Venturino, Hamilton, & Dverchak, 1989). SA takes inputs primarily from the operating environment (the situation itself), while secondary inputs such as motivations, operator capacity, and workload adjust the SA mental model. In turn, the operator makes a decision based off his SA and similarly colored by those secondary inputs. The resulting decision leads to an action, which alters the environment/situation and the cycle begins again.

As one would expect, pilot and aircrew SA is highly related to the dimensions of space and time (Endsley M. R., 1988a; 1995a). Aviation is inherently and naturally spatial in nature. Navigational position, altitude, speed, and heading naturally come to mind, and is frequently invoked in the aviator's priorities to 'aviate, navigate, and communicate' in that order. That is, fly the airplane first (altitude, attitude and airspeed), then navigate it, and then worry about other tasks, such as radio traffic. But, as SA is built up over time, it considers events that happened in the past to influence the mental model of the present and project a future status. Even non-visual observations such as written procedures, listening to radio traffic, etc., correspond to some mental model of space and time. However, the operator must maintain analytical awareness in order to

project his mental model forward (Endsley M. R., 1988a). SA regarding system status, malfunctions are highly analytical, and even observations in the space-time realm involve some degree of analysis.

Levels of Situation Awareness

Situation awareness (SA) is more than the possession of many pieces of data: it must be processed into some coherent understanding that is valid both in the present and in future tense (Endsley M. R., 1995a). Thus, multiple levels of SA exist as shown in Figure 4: Level 1 or perception, Level 2 or comprehension, and Level 3 or projection. The first and most basic level is detection or perception of conditions in the environment along with basic characteristics of that observation (Endsley M. R., 1988a; 1995a). This could be observing an instrument reading, noticing a warning light, terrain or other aircraft, or hearing a radio call.

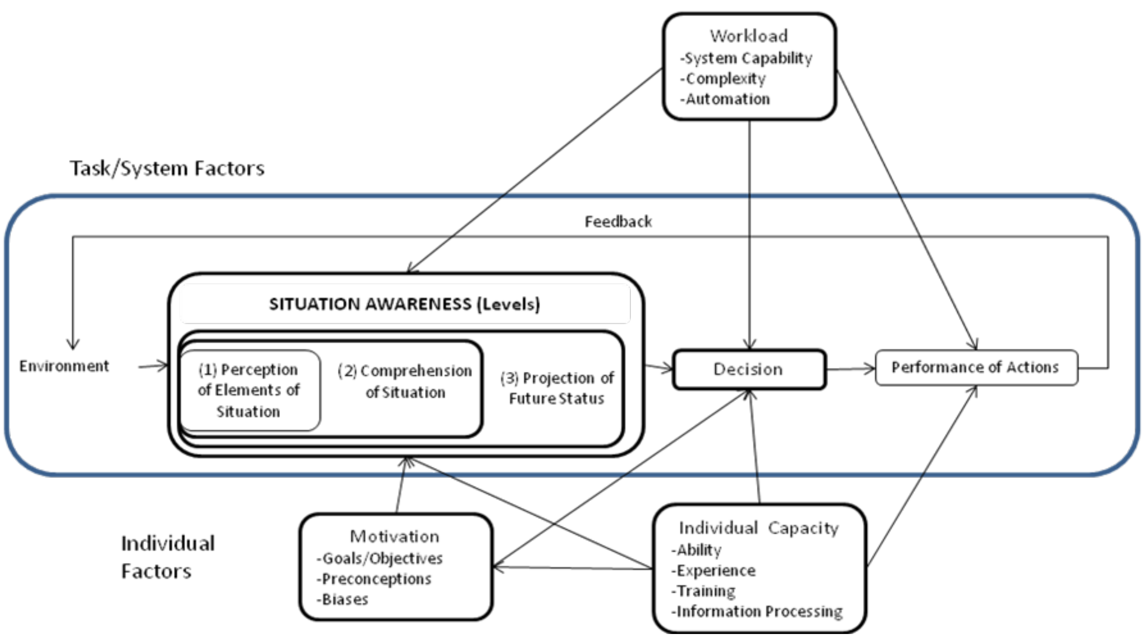

Figure 4: Situation Awareness/Decision Making Model (Endsley M. R., 1988a; 1995a)

The second level of SA involves comprehension of the meaning of those observations (Endsley M. R., 1988a; 1995a). For example, the warning light indicates that a system has failed, the fuel gauge indicates available range and time, the instrument reading describes aircraft performance, and the radio call relays an air traffic control (ATC) clearance. Because levels of SA build upon each other, poor perceptional SA makes comprehension much more difficult. Aircrews face incomplete information, conflicting data, and data incongruent with the established mental model, the resolution of which takes a great deal of effort (Adams & Pew, 1990). Spatial disorientation exemplifies a potentially hazardous condition in which the pilot's mental model is incongruent with the real world and conflicts with the information displayed by his instruments resulting in confusion about the actual aircraft attitude.

The third and highest level of SA projects this comprehension towards some future status (Endsley M. R., 1988a; 1995a). Is aircraft performance deviating from required parameters? Will that system failure prevent mission accomplishment? Based on the ATC clearance, what kind of future delays, constraints, and conflicts could arise? This highest cognitive level of SA joins cognition with decision making and action.

Low SA can be attributed to certain failures unique to each level. Failure to correctly perceive information (Level 1) may be caused by unavailable data, data that is hard to detect, a failure to observe available data, misreading data, or memory loss. A failure to comprehend information (Level 2) can be caused by a poor mental model, incorrect use of a mental model, or over-reliance on incorrect variables. Failure to project a future status (Level 3) stems from poor comprehension or an inaccurate

projection of existing trends since people are generally poor at prediction (Endsley M. R., 1999).

Attention, Capacity, and Situation Awareness

Available SA, just like mental workload capacity, is a product of the pilot's previous training and experiences, but is susceptible to preconceptions, biases, and objectives and individuals possess different abilities or capacities to obtain and maintain SA (Endsley M. R., 1988a; 1995a). Non-routine and unpredictable situations, such as combat, demand effective integration of large quantities of information on a limited cognitive capacity to process (Secarea, 1990; Endsley M. R., 1995a). Cognitive theory applies to SA capacity in much the same manner that it applies to mental workload capacity. While each operator may have different innate abilities to make observations, such as good eyesight or good spatial processing abilities, several factors can affect how readily a given operator acquires SA.

It would be reasonable to assume a pilot has observed a warning light simply because it is in his field of view. However, even cues in the normal field of view can be missed if they are too subtle or if the operator is not paying sufficient attention to it (Kahneman, 1973). If a pilot notices the light from another aircraft at night, but the aircraft's relative position appears to be fixed in the windscreen, then the pilot might assume that light might be a star or a street light. But, if that light appears to move across the screen, the pilot's attention would naturally be drawn to it, and thus determined to be another aircraft. Similarly, a system status change may go unnoticed if the indication is subtle (i.e. a gauge moving slightly, dim light, etc.), yet most pilots would immediately

recognize a flashing “Master Warning” light located prominently in the middle of the normal field of view—especially if it was accompanied by an audible warning tone.

Even perfect cueing will not add to SA if attention is not devoted to it. Information overload can overwork the operator but also overwhelm the senses or dull them to similar stimuli. An operator listening to multiple radios simultaneously with frequent intra-cockpit communications cannot process all the information being forced onto one (auditory) cognitive channel. Thus, the operator must prioritize the demands for single mental resource (Endsley M. R., 1995a). Conversely, the operator can become desensitized to frequent, or nuisance warnings, thus negating the effectiveness of those warnings (Billings, 1991; Wiener & Curry, 1980).

For competing attention demands an operator employs strategies to prevent information overload. Indeed a human operator’s capacity for attention is somewhere between 2-40 bits per second--far lower than the ability of the environment and modern cockpit systems to present them (Lovesey, 1995). Attention (and therefore SA) priorities depend of the determined relevance, implications, and urgency of the received data (Adams & Pew, 1990). The pilot might not pay much attention to an element until its status changes (i.e. noticing an unusual sound or handling characteristic). Instead of attempting to continuously monitor the status of all indicators, gauges, and displays equally, an operator chooses to sample instrumentation on a priority basis. The pilot’s instrument “cross-check” prioritizes aircraft attitude, then other measures of performance (i.e. heading, altitude, etc), then other mission systems (AFMAN 11-217, Vol 1, 2010). The pilot therefore samples higher priority instruments more frequently than lower priority instruments. Thus, limited pilot attention is devoted to elements in the

environment based on how they contribute to overall success based on the pilot's goals (Fracker M. L., 1989). Because of the prioritization of attention, the operator is much more likely to perceive changes to things he is actively observing or engaged in (Adams & Pew, 1990).

Attention can be split between environmental elements that demand different cognitive channels as stated in Wickens' Multiple Resource Theory (2002). The performance-arousal function also applies to attention and level 1 SA in much the same manner as it does in Figure 1. A sufficiently bored operator may simply not be paying attention, trusting that the situation will continue to proceed normally. Yet further arousal can stimulate an individual to commit more resources to attention and actively acquire SA (Kahneman, 1973). No current criteria exist to determine the required level of SA needed to obtain a desired level of performance (Pew, 1991). Thus, less than perfect SA causes the operator to assume a level of risk for error. Good SA increases the probability of good performance, but does not guarantee high performance because other factors are also at play (Endsley M. R., 1995b).

The act of perceiving an environment, comprehending it's meaning, and projecting it forward into a hypothetical, yet actionable future state imposes a heavy load on the operator's working memory (Wickens C. D., 1984; Endsley M. R., 1995a). This is especially true when the operator is rapidly introduced into a novel environment. This reliance on working memory creates a crucial attention bottleneck, which is inextricably tied to SA (Fracker M. L., 1989). Thus the act of attaining SA induces workload (Adams & Pew, 1990; Colombi, Miller, Schneider, McGrogan, Long, & Plaga, 2011; Endsley M. R., 1993). While the process of SA requires effort, and therefore work, it is not overt in

the manner that task-imposed workload is observable. The operator must use untasked spare time to acquire SA and perform relevant planning, yet this time may not be observable, let alone predictable (Colombi, Miller, Schneider, McGrogan, Long, & Plaga, 2011).

To mitigate demands on working memory, training, expertise, briefings are used to push those demands into the realm of long-term memory for storage and easier access. Continued exposure to the environment through training, experience, or mission repetition makes the environment routine, reducing the cognitive burden for acquiring SA. However, since long-term memory is not available when an individual is confronted with a novel situation, the burden of processing must shift back to working memory, which consumes more attention resources (Endsley M. R., 1995a; Adams & Pew, 1990). Other situations where SA is very low or erroneous, requires significant, if not enormous effort (i.e. workload) to correct, However even with a great expenditure of effort, an increase of SA is not guaranteed (Endsley M. R., 1993). An expert would have a higher likelihood of observing a similar situation, thus driving down the number of occurrences of novel situations with its attendant workload burden. In another setting, the pre-mission briefing sets expectations as to what will happen as well as contingencies that could arise. Thus, when an environmental cue appears, the pilot recognizes it faster if it was briefed than an unexpected cue. However, due to confirmation bias, if an element contradicts or otherwise disagrees with the preconceived expectation, then there is a higher likelihood of delay in perception or comprehension errors (Jones, 1977). Decision bias based on prior experience is an issue to SA when expectations cause the operator to ignore or misinterpret data to form an inaccurate mental model (Einhorn & Hogwarth, 1981).

Both long- and short-term memory play a role in how an operator builds SA (Endsley M. R., 1995a; Adams & Pew, 1990). The more developed memory stores a larger database of patterns from which to compare environmental cues. Better pattern recognition allows for faster recognition and perception of an element, or a richer comprehension of that element and what it could mean to the operator's future (Endsley M. R., 1995a). Pattern development can lead to automatic processing which can occur with conscious attention and a minimum of resources (Logan, 1988; Adams & Pew, 1990). Even basic decisions can be so habitual and automatic that the operator may not even recall the decision itself. Patterns and environmental cues can become so automatic that the operator may develop perceptional SA without knowing how he obtained that knowledge (Endsley M. R., 1995a).

Even when specific elements of SA are unknown, a pilot can still make decisions and predictions based off of very general knowledge and refine his mental model as more information becomes available and SA increases (Endsley M. R., 1995a). The confidence level of the information is an important aspect of SA because it determines how much more information is required to make a decision and influences the outcome of that decision (Endsley M. R., 1995a; Norman D. A., 1989). For instance, a pilot may only have knowledge of generalized enemy weapons systems capabilities and doctrine. His pattern of observation might be oriented towards finding the specific location of threats, which was refined because he has a better idea where to look (or even where not to look). When something suspicious—a radar return, an aircraft silhouette, or movement on the ground—is observed, the range of possibilities is constrained by general knowledge allowing for faster processing of that observation.

Just like workload capacity theory, expertise, training, and stress affect decision quality and SA. When presented with meaningful information, experts perform better, have better SA, and make better decisions (Adams & Pew, 1990; Endsley M. R., 1995a). Training and experience provide experts with a wider array of historical patterns that may closely match the current situation, more mature decision strategies, and require less effort to arrive at a given decision compared to the novice (Endsley M. R., 1995a). However, when information is meaningless or lacking altogether, or the situation is novel, the advantages of expertise are negated and expert versus novice performance approaches parity (Secarea, 1990; Hart, 1986; Kramer A. F., 1986; Lanzetta, Warm, Dember, & Berch, 1985; Ortega, 1989; Endsley M. R., 1995a). Stress and distractions can adversely affect decision quality (Wickens, Stokes, Barnett, & Hyman, 1988). Thus, external factors can simultaneously affect workload, SA, and decision making similarly.

Workload and Situation Awareness

Experienced workload impacts the amount of SA available to the pilot at any given time (Endsley M. R., 1993). It is reasonable to conclude that a pilot in an overloaded condition devotes a great deal of mental effort towards task management at the expense of observing and perceiving the environment around him. Workload impacts not only SA but the ability to make decisions and perform follow-on actions (Endsley M. R., 1988a). Because acquiring SA requires work, SA is both the result and generator of work (Endsley M. R., 1993). However, just as in workload-performance and attention theory, this is not to say that high workload necessarily results in low SA. While overload will result in poor performance, low SA may not necessarily result in poor

performance if the element of lost SA is not relevant to the task at hand (Endsley M. R., 1993).

If workload and SA are to be measured together, Endsley (1993) suggests that using complimentary methods may not be enough, and that the linkage between workload and SA are quite complex. Workload only measures how hard a person is working, not to what ends, or benefits, that work accomplishes (Endsley, Selcon, Hardiman, & Croft, 1998). For example the Subjective Workload Assessment Tool (SWAT) and subjective SA tools used together can suggest that an operator expends more effort to maintain a constant level of SA when task difficulty increases (Endsley M. R., 1993; Fracker & Davis, 1990). Workload may only impact SA as it approaches overload (Endsley M. R., 1996). However, while workload and SA are independent constructs, they show positive correlation, as measured in a study with NASA-TLX and the Situation Awareness Rating Technique (SART) (Endsley M. R., 1988c; 1993; Selcon, Taylor, & Koritsas, 1991). This correlation is not precise, nor is it consistent, partially due to the covariance of human performance against workload and SA. Endsley (1993) found significant dissociation between SWAT and the Situation Awareness Global Assessment Technique (SAGAT, described in the section: Measuring Situation Awareness) similar to dissociation found by Fracker & Davis (1990). During simulated air combat scenarios, the six test subjects each experienced workload values differently, but predominantly found high SA during periods of low workload and low SA during periods of high workload (Endsley M. R., 1993). SA can also be measured from an adaptation of the Subjective Workload Dominance technique (SA-SWORD) (AFRL, 2002).

Workload versus SA can exist in four distinct regions (Figure 5), sometimes disassociated from each other depending on operator capacity and motivation, system designs and the nature of the task itself (Endsley M. R., 1993). An unmotivated or inattentive operator may have low SA despite low workload. Low SA can also occur when the operator is confronted with too many tasks and SA demands are approaching overload. If that same operator experienced high, but attainable workload, it is possible to actively maintain high SA. The ultimate workstation design goal allows the operator to attain high SA with low workload, but the greatest challenge is maintaining that high SA during unavoidable periods of high workload (Endsley M. R., 1993).

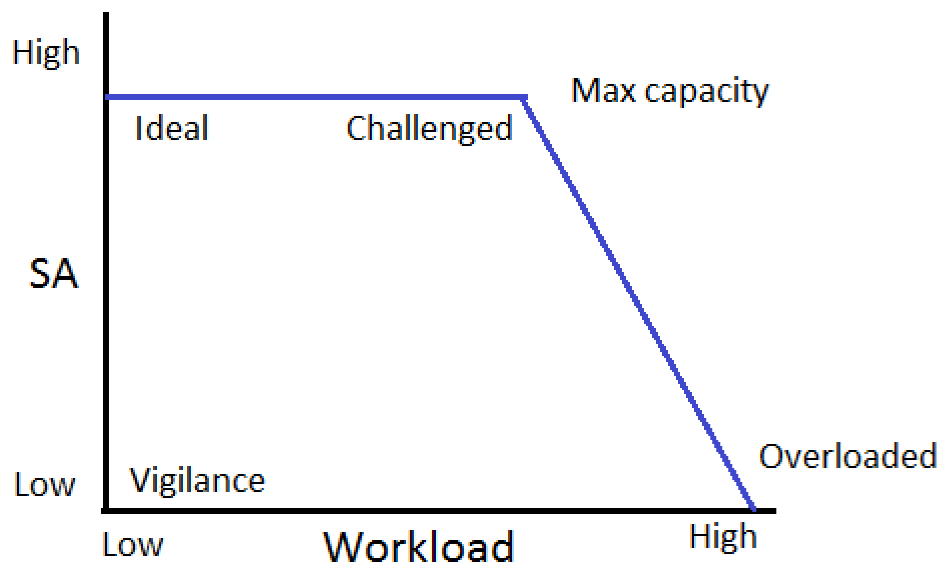

Figure 5: Workload vs. SA(Endsley M. R., 1993)

Cockpit Design, Automation, and Situation Awareness

Because of the critical effects situation awareness has on mission outcome and survivability, designers and operators both have a vested interest in maintaining a high

level of SA. Operators develop procedures and train to maximize the use of all available tools and observations to increase SA. Designers can incorporate heads-up displays (HUD), multi-function displays, automation, expert systems, advanced avionics and sensors to provide more information in a more useful manner (Endsley M. R., 1988a). In this regard, for a given task, all cockpits are not created equal. Cockpit design affects both the number of required tasks, the workload of those tasks, and the information provided to the operator during their completion (Endsley M. R., 1995a). Automation and intelligent cockpits can tailor information needs or perform support functions based on the required situation (Secarea, 1990).

In one study pilots strongly preferred the cockpit display setup that was subjectively rated to have the best SA (Hughes, Hassoun, & Ward, 1990). Other sources of information, such as moving map displays or datalinks add to the quantity and quality of data available to aircrew. Datalinks can take many forms (not all of which are compatible), and many datalink programs exist in military aircraft and have been considered for the C-130, such as High Power Waveform (HPW), Combat Track II (CT2 or CTII), Real-Time Information in the Cockpit (RTIC), Situational Awareness Data Link (SADL), Link 16, SAMS-ESA, Airborne Broadcast Intelligence System (ABI), Joint Tactical Information Distribution System (JTIDS), Tactical Digital Information Link (TADIL), Military Internet Relay Chat (mIRC), (Linson, 2010; AFTTP 3-3.C-130E/H, 2010; Monto, 2001; Nielson, 2005; Poole, 2008; Redenius, 2011; Sexton, 1998; Talley, 2012). However, the mere quantity of information is not the only factor in developing SA—indeed too much can cause overload where less important information precludes the pilot from concentrating appropriate attention on important information —

but how well the operator perceives and comprehend that data into something meaningful (Endsley, Selcon, Hardiman, & Croft, 1998).

Simply by reducing the number of places a pilot is required to scan within the cockpit, increases attention resources available to the remaining scan areas. Thus a glass cockpit that can provide higher information density simultaneously reduces the workload required to attain SA but provides more SA in the same field of view. However, if the pilot neglects to maintain a scan elsewhere and becomes dependent or fixates on those information sources (namely, the HUD), then SA remains limited (Haynes, 1998; Shinaberry, 2013). Automation, while reducing workload, can place the pilot out of the feedback loop, which can result in delayed or missed cues (Endsley M. R., 1996; Norman D. A., 1989). Automation can also increase feedback or provide new methods of communicating feedback, which may alter how an operator must assimilate that data (Endsley M. R., 1996). Feedback comes in many forms, some of which may not be obvious to the designer or operator at the time of development. For instance, the F-16's fly-by-wire controls prevented vibration feedback that may have been felt in traditional mechanical flight controls as the aircraft approaches a stall (Kuipers, Kappers, van Holten, van Bergen, & Gosterveld, 1989). Thus, designers design other feedback mechanisms, such as stick-shakers and stick-pushers to augment information already present on other displays, such as raw airspeed or angle of attack (Kantowitz & Sorkin, 1983).

Pilots who become passive observers miss the SA developed by actively gathering and processing information (Endsley M. R., 1996). Research shows that passive information processing is inferior to actively devoting attention resources and

Level 2 SA was lower in automated systems despite the similar availability of Level 1 SA elements (Slamecka & Graf, 1978; Cowan, 1988; Endsley & Kiris, 1995). Many of the aircraft accidents described earlier in this chapter (and hundreds more) can ultimately be attributed to, or prevented by, SA despite the causal role of automation.

Ideally, a modern glass cockpit (and its attendant automation) must serve to support the development of SA (Adams & Pew, 1990). However, while automation might condense the pilot's scanning region, consolidate information, and reduce workload, the associated reduction in attention demand, coupled with a potential for complacency and information filtering can reduce SA (Parasuraman, Sheridan, & Wickens, 2000). By changing human behavior in the cockpit, automation affects vigilance and complacency (related to attention invested), allows the human operator to assume a more passive role, and alters the nature of the feedback loop (time, quality, or form) (Endsley M. R., 1996). While this could improve operator SA, depending on the tasks and means available to acquire SA, this could also place the operator out of the feedback or decision loop.

Situation Awareness and Decision Making

While situation awareness reflects a snapshot in time, it is a continuing process or cycle to observe, comprehend, and project in order to update and refine the mental model (Endsley M. R., 1988a). This refinement process is closely linked to decision theory, and especially the OODA loop. To resolve a complex problem with a preferred outcome based on situational responses, a decision maker follows a perceive-plan-act cycle (Secarea, 1990). First and foremost, the decision maker must classify and understand the situation (Endsley M. R., 1995a; Klein, Calderwood, & Clinton-Cirocco, 1986). Col.

John Boyd defined an observe-orient-decided-act (OODA) loop to describe the decision making process in an air-to-air engagement (Figure 6). The pilot who won the engagement made better decisions quicker than his opponent could react (Osinga, 2006). Thus the winning pilot controlled the initiative and forced his opponent into a less organized and ultimately loosing set of reactions.

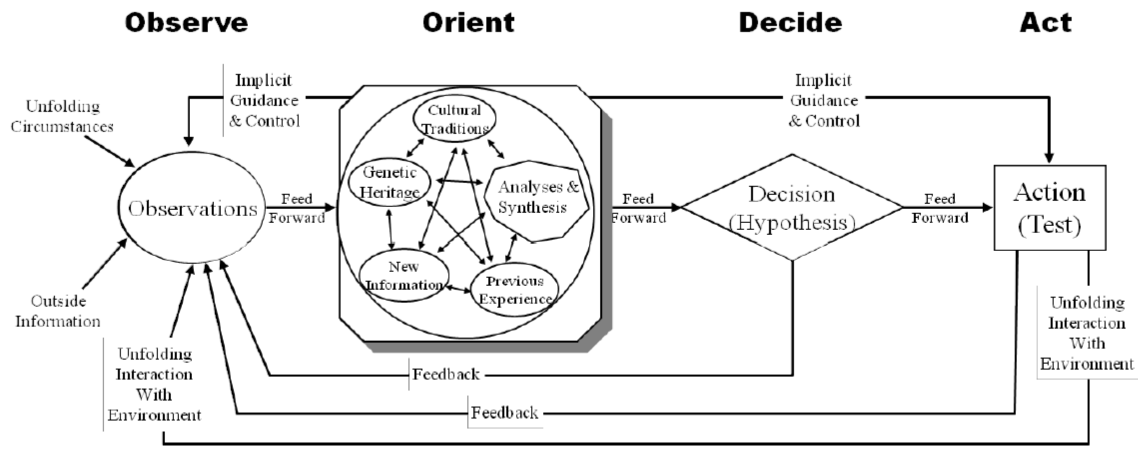

Figure 6: OODA Loop(Boyd, 1995)

Simply making decisions faster is not relevant if SA is inaccurate, since the resulting decisions, therefore actions, would be inappropriate (Endsley M. R., 1995a; Osinga, 2006). Failure to make adequate decisions can lead to aircraft accidents and combat losses. Poor decision making contributed to the shoot-down of Iranian airliner by the USS Vincennes (also mentioned in the automation section) because of poor SA due to a lack of good information available (Klein G. A., 1989a).

Perception, or observe and orient, relate to Endsley's first and second levels of SA, respectively. Projection, or level 3 SA formulates the basis of making the actual decision which the operator executes in the final step of the OODA Loop. Perhaps the

most crucial aspect in the OODA Loop is the operator's ability to quickly and accurately reassess conditions and iteratively develop his SA once that decision was put into action.

Indeed time pressure is a significant factor in decision making. One major solution to shortening the cycle (and achieve decision superiority) is to simplify the situation, or at least the perception thereof (Secarea, 1990). This can be done through pattern substitution, selective use of information, or using information in a more surface-level or shallow sense (Veltman, 2001). Another strategy is to shorten the time it takes to reach a decision. In a study, 95% of tactical decisions by ground commanders featured matching the situation to a memorized pattern instead of a more deliberative decision-making process (Kaempf, Wolf, & Miller, 1993). Individuals will try to use pattern matching as a heuristic for faster decision making; the results of which could come instantly or take considerable effort to reach(Klein G. A., 1989b; Hinsley, Hayes, & Simon, 1977). Furthermore, heuristic decision-making can fall victim to various cognitive biases. A time-constrained decision-maker is more likely to apply the sunk-cost fallacy to previously made decisions or apply a confirmation bias to evidence validating that decision (Veltman, 2001).

Thus, a pilot with a superior observational (level 1) SA and orientation (level 2) of his situation is likely to arrive at a decision sooner and with better quality inputs. Conversely, a pilot with poor SA would have poor performance unless the pilot realizes this (an act that would take a certain self-awareness) and takes corrective action (Endsley M. R., 1995a). Unless of course, the opposing pilot has even lower SA or the element of SA is irrelevant to the specific situation (Endsley M. R., 1993).

Humans are not apt at effectively reacting to random and unpredictable changes in their environment rapidly (Aretz, Guardino, Porterfield, & McClain, 1986). In an often-changing and dynamic environment, the difficulty of obtaining and maintaining SA is far greater than in a more stable and static environment (Endsley M. R., 1995a). Perfect situation awareness would naturally lead to superior decision making, yet obtaining perfect SA would require unlimited resources (Endsley M. R., 1988a). While a common set of core SA elements exists across any mission set or any part of a particular mission (i.e. aircraft performance, navigation, or system status), the relative priority and immediacy (i.e. immediate, intermediate, or long-term) of these elements are situation dependent (Endsley M. R., 1988a). The art of maintaining SA rests with the operator's ability to direct finite attention resources at the appropriate cues, observations and related tasks (Adams & Pew, 1990). This chore can become quite difficult if multiple high-priority tasks are competing for attention.

In order to mitigate demands for attention and SA, operators prioritize which elements of SA are most relevant to the situation at hand. During a mission, pilots prioritize and re-prioritize where to devote finite resources as the mission evolves (McDaniel, 1996). Pilots flying basic missions require SA regarding systems health, fuel status, navigational position, other air traffic, weather, and airfield conditions, just to name a few. If a pilot were flying a tactical mission, such as a formation low-level to an airdrop, then he requires SA on terrain and obstacle clearance, time status, airdrop parameters, formation position, and actions of the lead and following aircraft in addition to the aforementioned SA of a basic mission. If this tactical mission were to occur in combat, then SA requirements would grow to include defensive systems status, surface-

to-air threat capabilities and locations, enemy disposition, and actions of applicable friendly and enemy forces. In low-level flight terrain avoidance is the priority element of SA for the pilots, but may not be so for other aircrew members. During a threat engagement, defeating the missile becomes the priority with the pilot de-prioritizing or ignoring many other elements of SA as his intention becomes focused on defending the aircraft. However if the pilot focuses too much of his attention on one element, he loses SA on other, often critical elements of SA. The warning light may be ignored for a short while until the threat is defeated, but it may indicate an engine or other critical failure. If a pilot loses SA about his terrain clearance or aircraft performance, then he may place the aircraft in an untenable situation or impact terrain.

The importance of appropriate prioritization of attention resources to capture the most relevant SA cannot be overstated. There are multiple documented cases of pilots defending against an enemy threat system only to collide with the ground, therefore doing the enemy's job for them (Kuipers, Kappers, van Holten, van Bergen, & Gosterveld, 1989; AFTTP 3-3.C-130E/H, 2010; McCarthy, 1988). Many SA failures are caused by intentional attention shifts towards other factors that a pilot (erroneously) believes is more important due to a false or outdated mental model. However, the process of prioritization requires an understanding of the "big picture" (Endsley M. R., 1999). Paradoxically, the pilot must have some overall SA in order to accurately spend attention resources to gain and maintain SA.

Team Situation Awareness

Many tactical aircraft, such as the C-130, employ an aircrew team to accomplish the mission under the command of a pilot (as aircraft commander). Even single-pilot fighter aircraft employ in formation under a flight lead. Each member of the team has different SA priorities and responsibilities. Priorities are divided amongst the team for specialization, but many tasks will necessarily overlap, and an individual's SA is not neatly confined to just their specialization. For instance, a pilot may be primarily concerned with aircraft performance parameters, formation position, and terrain clearance. The navigator is primarily concerned with navigation, time status, and to some extent terrain clearance, but the pilot also shares these concerns to some degree. A flight engineer may primarily concern himself with fuel status, system health, and troubleshooting any faults, yet he may also concern himself with terrain clearance and aircraft performance as it affects safety of flight (perhaps not to the same level of scrutiny as the pilot's), and to an even lesser extent, processing navigator inputs. However if there is a system fault, then both the engineer's and pilot's attention, and thus SA priority, may shift to resolving the dealing with the fault, while the copilot and navigator continue to fly the mission. Thus, each member on the aircrew has overlapping areas of SA which contribute to a larger, shared team SA (Endsley M. R., 1995a).

However, SA is only as strong as the overlaps between required team members (Endsley M. R., 1995a). While a navigator may not require SA on systems health, if that navigator had perfect positional SA that was never shared with the pilot, then the pilot is still lost. In another situation one operator may have a critical piece of information (i.e. the navigator is the only person who can see the weather radar, or the pilot and copilot

have different displays presented at the time) which must be relayed to other relevant crew members. The process of relaying information to build team cohesion and SA is complex and partially captured in Crew Resource Management (CRM) training.

The systems designer can significantly change the quantity and quality of information sharing in the cockpit or between aircraft. Mosier and Chidester (1991) found that better performing teams actually communicated less than poorer performing teams, alluding to an efficiency of communication and group dynamics. Efficient communications result in a much higher signal-to-noise ratio; thus fewer words are needed to convey richer context. One element unique to team SA is that individual members have different goals and motivations, as well as capacity to perform work (Tremblay, Breton, Vachon, & Allen, 2012). While the nature of interpersonal interactions are complex and nearly impossible to predict, certain conclusions regarding team SA can be made. It is tempting to assume that synergistic SA effects can be realized in team settings, but if all members of a team possess identical information, there is no net gain in Level 1 SA. Indeed the shared mental model is distinct from the sum of its parts (Cooke, Stout, & Salas). However, similar information may be present to multiple members of a team, but not fully realized (i.e. both pilots have access to identical flight instrumentation, but the pilot-not-flying recognizes and reports a deviation to the pilot-flying, thus improving his SA). Ironically, the process of specialization and funneling information to the team can consequently degrade individual SA (Tremblay, Breton, Vachon, & Allen, 2012).

Not all members of the team need to be human. In a sense, automated and intelligent systems are part of a pilot's team. Just as levels of automation (discussed

earlier) exert different levels of control, decision support automation can serve as an assistant, associate, or coach—even changing levels of support and control depending on the specific situation (Veltman, 2001).

Measuring Situation Awareness

Measuring total SA poses a conundrum. At first glance measuring SA could be done with similar techniques to workload measurement: subjective questionnaires, asking a pilot in real-time during a simulation, and physiological measurements. For instance, an electroencephalogram (EEG) can measure electrical brain activity or eye tracking can measures if the operator is looking in the right place, but a correlation to perception awareness (level 1) is difficult, while comprehension and projection (levels 2 and 3) are elusive (Endsley M. R., 1988a; 1995b). That is, it may be possible to physiologically determine whether information is registered, but not possible to identify comprehension (Endsley M. R., 1995b). Performance measurements are objective and easy to obtain, but their potential for dissociation, as described above, makes establishing a correlation/causation relationship difficult (Endsley M. R., 1995b). An externally injected task could be used to evaluate SA in a controlled manner: a piece of information can be added or removed from an operator, and then both the response time and actions taken could be evaluated. Conversely, any internal observation of deviations from prescribed parameters is a specific measure of performance, which has more significance than performance measured generically or on the whole. However, performance is highly variable and subject to several inputs in addition or not related to SA (Endsley M. R., 1995b).

Questionnaires, while inexpensive and easy to use, are subject to more bias than workload measurements, since the experimenter is essentially asking the pilot not necessarily what he knew about his environment, but also how many unknowns remained unknown (Endsley M. R., 1995b). The phrase “ignorance is bliss” rings true: a pilot who has low SA or lost SA may not realize he has done so until after the fact, if at all (Endsley M. R., 1988a). This is especially true of self-assessments. If a trial went well, that may influence a test subject to report favorable SA, which may or may not be the case. Subjects can show biases based on the weight of importance they place on different elements of SA (Endsley M. R., 1995b). Subjective evaluation conducted after the experiment can be rationalized or generalized, thus resulting in inaccurate perceptions, especially as detail is lost of forgotten (Nisbett & Wilson, 1977). However, questionnaires can be used objectively and compare perceived SA against measurable global data points (Hermann, 1984). Automatic processing potentially masks reporting on comprehension of elements that exist in the operator’s subconscious (Endsley M. R., 1995a). Furthermore, SA itself is dynamic and complex involving so many factors that an overall assessment of low, medium, or high may be inappropriate. Real-time questioning of a pilot’s SA state, or externally injected tasks, adds more workload and could artificially detract from the SA available (Endsley M. R., 1988a; 1995b). One subjective workload assessment was used to develop the AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM). During the AMRAAM Operational Utility Test (OUE), SA was self-evaluated by the test subjects and also by a trained observer (McDonnell Douglas Aircraft Corporation, 1982). However in a re-evaluation of the OUE data showed a suspected bias between good performance and subject-reported high

SA (Venturino, Hamilton, & Dverchak, 1989). In a similar approach, a third party observer can independently rate the workload of a test subject. While removing some of the biases associated with self-assessment techniques, the observer cannot determine the subject's SA level unless some overt act, statement, or response from prompting occurs (Endsley M. R., 1995b).

Another subjective method, the Situation Awareness Rating Technique (SART) attempts to connect workload to SA by asking test subjects to rate the supply and demand relationship for attentional resources. As such, a positive correlation has been shown between SART and performance measures (Selcon & Taylor, 1990). SART is also highly correlated with subjective assessments of operator confidence levels (Endsley, Selcon, Hardiman, & Croft, 1998). SART has 14 components relevant to pilot SA which are evaluated on bipolar scales in three categories: demand on operator resources, supply of resources, and understanding of the situation. These categories are summed to provide an aggregate SART score (Selcon & Taylor, 1990; Endsley, Selcon, Hardiman, & Croft, 1998). Thus SART includes a subjective workload assessment as well as an SA assessment. While this linkage is handy, the subjective methodology of SART is susceptive to drawbacks commonly associated with subjective means, such as the "ignorance is bliss" fallacy(Endsley, Selcon, Hardiman, & Croft, 1998). Because of the combined scales, SART may not provide significant causality to explain the dissociation between workload and SA and may leave the experimenter wanting for more data (Endsley M. R., 1993; Endsley, Selcon, Hardiman, & Croft, 1998; Selcon, Taylor, & Koritsas, 1991).

Endsley (1988a) developed an objective method of measuring situation awareness called the Situation Awareness Global Assessment Technique (SAGAT). SAGAT has been used to study human-machine interfaces (Bolstad & Endsley, 1990; Northrop Corp, 1988; Endsley M. R., 1988a; 1989; 1990a). In SAGAT, pilots are asked to fly a mission scenario in a simulator. At random points in time the simulator is paused and display screens are blanked. The pilot is then asked a series of questions regarding the situation at that instant. These questions cover both the immediate, short-term environment and elements requiring recall from earlier in the simulation. The process is repeated several times with a large question bank selected at random to sample along primary and less important elements of SA. The pilot's responses are compared to simulator data to evaluate his perception against reality(Endsley M. R., 1988a; 2000). Because questions are asked as the simulation is paused, SAGAT is a low-intrusive form of evaluation that also samples in real-time without the loss of fidelity of a post-experiment questionnaire. The nature of the questions can also evaluate level 1, 2 or 3 SA (Endsley M. R., 2000). The stochastic time interval and sampling recall prevents the test subject from anticipating responses (Endsley M. R., 1995b). With a statistically significant pool of responses and computer-captured performance data, SAGAT becomes an objective method of SA evaluation. It addition to being an empirical analysis of existing prototypes, SAGAT has predictive validity (Endsley M. R., 1990a). In a study of fighter cockpits comparing SART and SAGAT, it was found that there was no direct correlation in results between subjective SART scores and objective SAGAT results (Endsley, Selcon, Hardiman, & Croft, 1998). For the same set of conditions, SART evaluations indicated higher SA for a given cockpit display, while SAGAT recorded mixed and lower

results for Level 1 SA. In the same test, the new cockpit display showed higher Level 2 and lower Level 3 SA for both means. Overall, SART, particularly the "understanding" component, correlated well with simple subjective self-evaluations for both sufficiency and confidence level. All SART components were inter-correlated with each other. Of the 13 variables collected during the SAGAT analysis of this experiment, each variable was found to be independent, which led the investigators to conclude that compiling a total SA score was not of particular value. Because of this, no clear relationship between independent SAGAT variables and the SART rating could be identified. However, the authors found that, despite the lack of correlation, SART was particularly useful for determining an overall SA score and would be useful in real-life flight testing, where SAGAT could be used to diagnose and detail specific effects at the human-machine interface (Endsley, Selcon, Hardiman, & Croft, 1998).

SAGAT has also been applied to human performance modeling (Plott, Endsley, & Strater, 2004). The SAGAT scoring method was incorporated into a task network for a battle station in a future ship design. The task network in question was written to store SA-related variables as a reflection of operator working memory. Various parameters were devised as contributing towards SA based on SAGAT questions, and these parameters could compose a total SA score. Because it is a simulation, the simulated operator had perfect memory and committed no errors, thus representing a best-case scenario(Plott, Endsley, & Strater, 2004).

Description of C-130H and C-130J Aircraft

The C-130H is an upgraded iteration of the C-130E aircraft produced through the 1960s. Within the C-130H fleet (produced since 1974) are several sub-variants, known as C-130H1, H2, and H3. The C-130H (all sub-variants) requires a basic crew of five: aircraft commander (pilot), copilot, navigator, flight engineer, and loadmaster (U.S. Air Force, 2003). The aircraft commander must be a pilot, but may sit in either the left (pilot) or right (copilot) seat. Duties and responsibilities for each crew position are described in Chapter 3. For most tactical missions, a second loadmaster is added to bring the typical combat crew compliment to six (AFI 11-2C-130, Vol 3, 2010).

The C-130J, which entered the USAF inventory in 1999, while bearing a similar external appearance to the C-130H, features such significant design changes that it is considered a different Mission Design Series (MDS) with a separate training and qualification program. The C-130J is a clean break from the iterative C-130 evolution, hence the "legacy" moniker applied to the A/B/E/H variants (Musser, 2013). Modern avionics and enhanced automation reduce the crew compliment to three: aircraft commander (pilot), copilot, and loadmaster (AFI 11-2C-130J, Vol 3, 2009; TO 1C-130J-1, 2009). Just like the C-130H, a typical combat crew adds a second loadmaster (AFI 11-2C-130J, Vol 3, 2009). Early operational experience shows the C-130J has an increased mission capable rate (93.9% versus 75%) and a reduced preflight time compared to the C-130H (Lockheed-Martin, 2005; Burgess, 2005; Oviedo, 2005).

The C-130J features some performance upgrades: a more efficient propeller, more powerful engine, and a Full Authority Digital Engine Controller (FADEC) which can command an automatic engine shutdown and/or automatically feather the propellers (TO

1C-130J-1, 2009). However, most of the improvement and upgrades to the C-130J are modern avionics. The C-130J features full color multifunction displays (MFDs), a heads-up display (HUD), a digital moving map, and integrated threat warning and systems monitoring features. The addition of autothrottles and an improved autopilot allows for autopilot-coupled formation flying. This represents an entirely new cockpit and a radical departure from legacy cockpit design. Conversely, the C-130H features several incremental upgrades to avionics subsystems, but still relies heavily on analog gauges. For a more detailed qualitative analysis of the C-130 series, refer to Appendix A: Description of C-130 Aircraft.

The two-pilot C-130J was anecdotally assessed by one officer to be 90% as capable as the C-130H with the autopilot-coupled SKE formation able to best take advantage of the advanced avionics (Burgess, 2005). Specifically threat detection and communications under high workload were considered the most significant limitations to a two-person cockpit (Burgess, 2005). In complex integrated combat environments, all aircraft radios are pressed into service, however each person can only effectively manage (transmit and receive) on one radio at a time. Because Pilot SA is built both visually and through radio communications, there is a higher possibility of important missed communications on smaller aircrews (Burgess, 2005).

On complex missions, such as an airdrop utilizing the Joint Precision Airdrop System (JPADS), another pilot or even a “legacy” navigator must be added to the C-130J to operate specific mission equipment (AFI 11-2C-130J, Vol 3, 2009; Hendrickson, 2008). Adding an additional crew member is not uncommon, as can be seen in contingency C-17 operations for both task distribution, ground operations safety,

operating extra command and control communications equipment, traffic, and threat scanning (Brockman, 2010). Augmenting a basic combat crew adds extra sets of eyes to scan for surface-to-air and air-to-air threats. This lookout doctrine is highly emphasized in the tactical airlift community and involves each member of the crew, including the loadmaster. Thus, because a scanner cannot see in all places at all times, having fewer scanners increases the possibility of missing threats, especially when other cockpit tasks must be performed (Burgess, 2005).

Discrete-Event Simulation

Discrete-event simulation (DES) is a software-driven tool that can analytically predict outcomes, or improve existing task flows without requiring the expense or existence of an operational prototype (Rusnock & Geiger, 2013; Mitchell, 2000). Because of its empirical nature, DES can corroborate other methods of workload measurement (Mitchell, 2000). Instead of a perfectly continuous simulation, DES runs many activity-based discrete time increments and calculates an output for each time step. Furthermore DES can be dynamic and stochastic, allowing real-world randomness to be simulated and dynamic decision pathways to emerge based on different input or stochastic conditions. In human performance modeling, DES is used to evaluate the interaction between human operators and machines, especially in measuring mental workload (Rusnock & Geiger, 2013).

The programmer first defines a mission model from a task network, which includes all mission tasks in sequence. Each task has an assigned operator, finite execution time distribution (a stochastic variable), and workload demand values assigned

to it. From this completed task network, DES can compute a time-based workload score. By applying relevant capacity theory and a defined operator capacity, and the overload conditions can be determined. This experienced workload dynamically correlates to a predictive human performance value. When a prototype becomes available for testing, the DES results can be reproduced and the DES validated against conventional workload measurements.

IMPRINT (Improved Performance Research Integration Tool) is DES software created after merging the functionality of several earlier software tools (WinCrew, MAN-SEVAL, and CREWCUT) developed by the Army Research Laboratory and is now the primary human performance modeling tool for the US Army (Mitchell, 2000; Cassenti, Kelley, & Carlson, 2010). In the IMPRINT software, a modified VACP scoring methodology is used (Table 5). Incremental and task workloads are scored with cumulative VACP scores (i.e. a task can have any combination of Visual, Auditory, Cognitive, etc components). Total workload is calculated by summing the workload values for each discrete task and across all tasks performed simultaneously. In addition to computing a time-distributed workload value, IMPRINT can include a multitude of user-defined variables that allow for model randomness over multiple runs. The programmer can code different decision pathways to dynamically change the critical path based on defined release conditions.

Table 5: IMPRINT VACP Values (Mitchell, 2000; Alion Science, 2013)

Scale Values	Descriptors
	Visual
0.0	No activity
1.0	Visually Register/Detect occurrence of image

5.0	Discriminate symbols, numbers, words
3.0	Visually inspect/check (discrete inspection/static condition)
4.0	Visually locate/align (selective orientation)
4.4	Visually track/follow
5.1	Read (symbol)
6.0	Visually scan/search/monitor (continuous/serial inspection)
	Auditory
0.0	No activity
1.0	Detect occurrence of sound
2.0	Orient to sound (general orientation/attention)
4.2	Orient to sound (selective orientation/attention)
4.3	Verify auditory feedback (detect occurrence of anticipated sound)
3.0	Interpret semantic content (Speech) Simple (1-2 Words)
6.0	Interpret semantic content (Speech) Complex (sentence)
6.6	Discriminate sound characteristics (detect auditory difference)
7.0	Interpret sound patterns (pulse rates, etc)
	Cognitive
0.0	No activity
1.0	Automatic (simple association)
1.2	Alternative selection
4.6	Evaluation (consider single aspect)
5.0	Rehearsal
5.3	Encoding/decoding, recall
6.8	Evaluation (considering several aspects)
7.0	Estimation, calculation, conversion
	Fine Motor
0.0	No activity
2.2	Discrete actuation (button, toggle, trigger)
2.6	Continuous adjustive (fight controls, sensor controls, etc)
4.6	Manual (tracking)
5.5	Discrete adjustive (variable dial, etc)
6.5	Symbolic production (writing)
7.0	Serial discrete manipulation (keyboard entries)
	Gross Motor
0.0	No activity
1.0	Walking on level terrain
2.0	Walking on uneven terrain
3.0	Jogging on level terrain
3.5	Heavy lifting
5.0	Jogging on uneven terrain
6.0	Complex Climbing
	Tactile
0.0	No activity
1.0	Alerting
2.0	Simple Discrimination
3.0	Complex symbolic information
	Speech
0.0	No activity
2.0	Simple (1-2 words)
4.0	Complex (sentence)

Algorithms embedded in IMPRINT allow for limited human performance measurements primarily based on total workload: time to complete a task, likelihood of task success, accuracy penalties, and task initiation time delays. These performance measurements show the effect of Wickens' Multiple Resource Theory, therefore conflicting channels will have different impacts to operator workload and performance than tasks that do not cause channel conflicts (Alion Science, 2013; Cassenti, Kelley, & Carlson, 2010; Mitchell, 2000). Operator capacities and overload threshold can be user-defined, and stressors, such as fatigue, environmental conditions, night vision goggle usage, or personal equipment (i.e. chemical warfare gear) can be included to further affect capacity. Finally, the programmer can chose to employ and compare workload strategies for each operator for the duration of the model. Strategy application and performance degradation do not have to wait until the operator is overloaded, but can be determined as the workload increases prior to overload (Cassenti, Kelley, & Carlson, 2010).

Another workload-performance DES is The Workload Index (W/INDEX). Like IMPRINT, it allows a crew station designer evaluate the workload design of a crew station layout or procedure. W/INDEX also made its debut during the Army's LHX scout helicopter in 1983, but was also applied to the Advanced Tactical Fighter and the National Aerospace Plane. It computes total workload by summing discrete tasks along the course of a mission profile in a subroutine called the Interface/Activity Matrix. However, while IMPRINT calculates workload anytime a task is started or stopped (therefore there could be dozens or hundreds of workload calculations per second if the task network is complex), W/INDEX displays a five second running average of workload

from half-second discrete time iterations. W/INDEX uses a scale resembling VACP: visual, auditory, manual, and verbal with values being assigned on a 1-5 integer scale based on the perceived attentional demand. However, while IMPRINT assigns descriptors to VACP values, the W/INDEX values are definition-less and arbitrarily assigned by the programmer. Just like IMPRINT, W/INDEX applies Wickens' Multiple Resource Theory and attention-channel conflict penalties to the performance output (North & Riley, 1989).

Because IMPRINT allows user-defined code and macros, further refinements in performance measurements can be made. Cassenti and Kelley (2006) experimented with effects on performance when multiple simultaneous tasks are performed. Their experiment showed that increased workload has a predictive impact on performance similar to the arousal and performance-resource function described in Figure 1 and Figure 2 (Cassenti & Kelley, 2006). Interestingly, IMPRINT predicted lower performance for low workload conditions, presumably showing an underload condition (Cassenti & Kelley, 2006; Cassenti, Kelley, & Carlson, 2010). In another study, a simple evaluation or judgment task was set before a group of test subjects and the measured error rate was compared against the predictive IMPRINT performance for the same modeled task. While the task itself was of constant difficulty, time pressure was varied to affect experienced workload. The task was changed for each experiment to evaluate correlation between different cognitive task loads: alternative selection, signal detection, simple and complex evaluations.

One of the earliest applications of IMPRINT for human performance and workload modeling was for the Army's Light Helicopter (LHX) development in the

1980s (McCracken & Aldrich, 1984). IMPRINT's predictive utility was also used to design crew station on the UH-60 helicopter (Bierbaum, Szabo, & Aldrich, 1989). The recent ascendency of unmanned aerial vehicles (UAVs) and remotely piloted aircraft (RPAs) has drawn considerable attention to pilot workload. While highly automated in basic flight, their mission—predominately Intelligence, Surveillance, and Reconnaissance (ISR)—is highly dynamic and can quickly potentially overload operators when engaged in real-time tracking. In several feasibility studies, workload from the control of a system of single or multiple RPAs was studied using IMPRINT (Colombi, Miller, Schneider, McGrogan, Long, & Plaga, 2011; Hunn, 2006; Hunn & Heuckeroth, 2006; Hunn, Schweitzer, Cahir, & Finch, 2008; Pomranky, 2006; Pomranky & Wojciechowski, 2007)(Scheider & McGrogan, 2011; Wickens, Dixon, & Chang, 2003). IMPRINT has also been used to evaluate robotic systems (Harriott, Zhang, & Adams, 2010; 2011; Harriott, Zhuang, Adams, & DeLoach, 2012; Cosenzo, Parasuraman, Novak, & Barnes, 2006), vehicles (Wojciechowski, 2006; Mao, Xie, Hu, & Su, 2013), and other systems. In an intelligence-related simulation, IMPRINT was shown to have good correlation of experienced workload with the NASA-TLX evaluation and a better correlation than physiological measurements such as EEG, mean flow velocity, and others (Rusnock & Geiger, 2013).

The C-130J has also been analyzed with IMPRINT. A sample single-aircraft airdrop mission was created using basic functions and modeled both the pilot and copilot. These functions included navigation to initial point (IP), navigation to the drop zone (DZ), the airdrop, and flying away from the DZ, along with sample communication tasks. The construction of the task network was derived from phone calls to and observations of

USAF C-130J units. Snapshots were used to capture data throughout the mission, such as periodic workload values and time spent heads-up versus heads-down (LaVine, 2010). This simulation showed during the baseline experiment that the pilot-flying spent 43% head's down managing tasks and 57% head's up ostensibly flying and observing, while the pilot-monitoring (the pilot not flying the aircraft) spend 25% heads-down, 41% heads up, and 34% unaccounted for or untasked. The workload graph depicted a sine wave of workload for both the pilot and copilot. This sine function increments up or down as a bloc when the mission moves into the next phase. While IMPRINT uses a default overload condition of 60 dimensionless workload units, the wave amplitude routinely exceeds 30 units, and the maximum observed workload value (at the airdrop release) exceeds 220 units (LaVine, 2010).

The next variation of this experiment had the simulated aircrew fly the same profile, but a change in drop zone must be programmed into the computer at 8 minutes into the simulation. Another iteration introduced a pop-up restricted operating zone (ROZ) that the aircrew must avoid. Since the pilot monitoring manipulates the computer, his workload increases considerably during the data entry phase. Part of this workload increase was the requirement for the pilot monitoring to make an adjustment to a laptop computer to display special use airspace, which drove more heads-down time. The experiment was run once again with a hypothetical digital moving map that negated the need for a laptop, which resulted in less workload to plot the ROZ and manipulate the navigation solution. In this experiment, IMPRINT proved the value in adding a digital moving map display to the C-130J (LaVine, 2010).

Summary

Human performance in aviation is a complex phenomenon. Performance may be simply the ability to maintain certain parameters or successful task completion. However, performance is often more nuanced and complex: incorporating proper decision making and building situation awareness (SA). Fundamental to performance in complex, changing, unpredictable, and lethal tactical environments is decision superiority. The pilot who can make better decisions, faster than his opponent, will likely win an engagement, best described by Boyd’s OODA loop. Essential to continued decision superiority is SA and having timely and proper feedback. Because SA underpins decision making and actions taken, it is the ultimate currency for performance in tactical aviation.

The relationship between workload and performance is well understood. Human performance modeling using discrete-event simulation has proven useful to predict workload, especially in systems where a prototype does not yet exist. While it’s possible to map a task network into DES during the design phase, if done early, the simulation results lack resolution. Furthermore, workload stems not just from overt cockpit tasks, but from activities that are not strictly contained within a checklist: operational tactics and procedures, maneuvering, communication, and SA building all require cognitive resources.

Specifically, the connection between workload and SA, while variable and dissociative, is not quantifiable in the design phase. Yet, if SA is the ultimate commodity to tactical aviation, how does an engineer design a cockpit to assure maximum potential SA? Furthermore, with the incorporation of modern glass cockpits providing more

information to aircrews and taking over larger shares of cockpit duties, how does the tactical aviator remain in the most optimal level of control instead of becoming complacent and outvoted by the machine he flies? Plott, et. al (2004) may have been the first to attempt to predict potential SA using DES, but to date, no known attempt has been made to deterministically determine SA from both the tasks that create SA and the workload levels that reduce it.

Finally, the C-130, an oft-overlooked workhorse, is at a unique juncture. Research on aircrew workload, SA, automation, and cockpit design typically focus on commercial aviation or single-seat fighters, yet the C-130 is not fully airliner, nor fighter. The ongoing transition of the USAF from the legacy C-130H, one of the last aircraft with a flight engineer and a navigator, to the modern C-130J operating with a cockpit crew of two pilots, provides a glimpse of how drastically automation has redefined aircrew roles. This is a perfect opportunity to contrast a highly automated system with one that emphasizes manual operation in a tactical mission profile.

III. Methodology

Chapter Overview

In order toevaluate the impact of automation on aircrew workload and situation awareness, two representative mission scenarios were chosen that adequately reflect the flight qualities of the C-130H and C-130J as currently employed. First, a task analysis elicits operators, task flows, and various decision points in order to construct a complete task network for each scenario. These task networks were modeled using the Improved Performance Research Integration Tool (IMPRINT), a discrete event simulation (DES) software tool. After model creation, the scenario simulations are run through IMPRINT, which output a time-dependent distributions for workload, situation awareness, and the relationship between the two. From these distributions, a qualitative analysis of the data, specifically describing workload "peaks" (i.e. abover normal workload variations) and general characteristics about SA can be made. Running multiple iterations through a *t*-test can tell us if the data is statistically significant in order to quantitatively answer our investigative questions.

Phase I: Task Analysis

The C-130 was chosen as the candidate platform for this experiment because of the author's familiarity with the airframe, cockpit variations, and simultaneous employment in the Air Force for identical missions between the legacy C-130H and the C-130J. Being a versatile tactical airlift platform, the C-130 has a wide variety of

mission sets that it is capable of performing. In virtually all missions currently employing a legacy C-130, either a C-130J is replacing the legacy platform or is planned to replace the legacy in the future.

For the purpose of this thesis, it would be impractical to study a side-by-side comparison of every mission set and special variant of the C-130 family. Furthermore, it would certainly be impossible to conceive and simulate every possible variation and scenario facing the aircrew. Thus, representative mission scenarios depicting a "typical" C-130 mission that depicts the differences in cockpit tasks were chosen. Two tactical airlift-unique mission sets stood out: formation airdrop and airland with maximum effort/assault procedures. Both missions encapsulate a significant percentage of tactical training time spent by Air Force C-130 aircrews.

Formation airdrop in inclement weather by use of station keeping equipment (SKE) exploits the difference in tasks associated with a pilot manually flying a formation position while simultaneously sending commands via push-button (C-130H) versus automatic formation position maintenance and control (C-130J). Maximum effort/assault airland demonstrates the unique capability of the C-130 and procedures to utilize austere and short airfields as well as the workload required to calculate tactical approach parameters and manage aircraft energy during the approach.

First, two representative mission scenarios were scripted: formation SKE airdrop, and single-aircraft maximum effort landing. Each of these mission scenarios ran parallel to a baseline function, "Basic Aircraft Control," which contained the most common tasks related to flying the C-130: manipulating the flight controls, scanning instruments and systems, routine navigation and formation position maintenance, scanning for enemy

threats, listening to radios, etc. A task analysis initially written in narrative form was diagrammed via UML activity diagrams (Appendix E: UML Activity Diagrams). This task analysis identified several operators, who are internal to the system, as well as external actors that influence the system. From this, task flows between the actors are identified, and some decision points can be established. Thus, a full task network formed for each scenario. Some of these decision points are:

- Is the aircraft below 10,000 feet? (Can the cabin be depressurized)
- Is the aircraft in a safe position to drop?
- Has the aircraft been cleared to drop?
- Has the aircraft been cleared to land?
- Has the aircraft met all drop "contracts?"
- Is the aircraft below design limit speeds for flaps, landing gear, or doors?
- Is the aircraft in visual or instrument meteorological conditions?
- System malfunction (either induced or random)
- Surface-to-air threat engagement

Operators simulated in each model are the cockpit crew (Pilot, Copilot, Flight Engineer, and Navigator for C-130H and the Pilot and Copilot for C-130J). The Drop Zone (DZ) Controller, Air Traffic Control (ATC), Loadmaster, and Formation Leader are selectively modeled as external actors. Actions of external actors are only pertinent where they initiate a task performed by an operator. Externally initiating tasks is important to show how tasks must be delayed for an external event (i.e. being cleared by

ATC to land or a command from the formation lead) or aircraft transit time (the Pilot cannot descend the aircraft until it arrives at the descent point).

The primary task flow is derived from applicable checklists in TO 1C-130H-1 and TO 1C-130J-1. These checklists were the basis for the critical path tasks as it related to a verbal challenge-response and cockpit switch actuation. Checklists were written for flight deck aircrew, which conveniently provided a break point for operator-external actor interaction. Using AFTTP 3-3.C-130E/H and AFTTP 3-3.C-130J, a time-sequenced mission flow identifies significant events in timeline format. This flow also identified which tasks could be performed in parallel to the critical path and releases for tasks in the critical path. The aircraft operating procedures provided required employment procedures, commands, and procedures not explained in the flight manuals or tactics publications. Finally, in addition to the author, four subject matter experts with experience flying each mission scenario (in both C-130H and C-130J) provided a context to stitch together tasks gleaned from each publication.

Phase II: Build Baseline Simulation Model

This task network is modeled in the discrete event simulation software, IMPRINT produced by Alion Science and Technology Corporation for the Army Research Laboratory. Designed as a product for the Army, IMPRINT has three related categories of actors, each with their own traits and analyses: Operators, Maintainers, and Supply/Support. However, only the Operators are applicable to this investigation. The cockpit crew represents the actors internal to the system. In the C-130J, this is the Pilot and Copilot, while in the C-130H, this is the Pilot, Copilot, Navigator, and Engineer.

In this study, the Pilot (C-130H and C-130J) acts as aircraft commander, flies the aircraft, initiates most checklists, and talks on the radio assigned to the formation frequency. The Copilot monitors the Pilot's flying performance, to include basic navigation and formation positioning. The Copilot manages radio assignments, manipulates SKE parameters, actuates the landing gear and flaps, and, in the C-130J, program and manipulates the navigation solution and troubleshooting through the Communication/Navigation/Identification-Management Unit (CNI-MU). The C-130H Navigator computes the airdrop release point, relays station keeping equipment (SKE) commands in conjunction with the Pilot, navigates the airplane (including maintaining an on-time status), initiates airdrop checklists, and manages the defensive systems. The Engineer is primarily responsible for monitoring aircraft systems health, troubleshooting malfunctions, preflight inspections, calculating takeoff and landing data (TOLD), and ensuring checklist completion. Each crew position assumes several overlapping roles that are not annotated in checklists or technical orders: threat scanning, basic navigation, monitoring aircraft performance, and ensuring safe operating parameters. Generic duties are described in (Table 6). Tasks performed by the C-130H Navigator and Engineer typically are assumed by C-130J avionics with data entry provided by non-flying pilot(s).

Table 6: C-130H & C-130J Sample Allocation of Tasks

<table>
<tr><th colspan="4">Basic Aircraft Control Tasks</th></tr>
<tr><th></th><th>C-130H</th><th>C-130J</th><th></th></tr>
<tr><td rowspan="11">Pilot</td><td colspan="2">Actuated flight controls (control yoke, throttles, rudder pedals)</td><td rowspan="11">Pilot</td></tr>
<tr><td colspan="2">Call for checklists</td></tr>
<tr><td colspan="2">Taxi aircraft (on ground)</td></tr>
<tr><td colspan="2">Monitor aircraft performance (observe attitude, altitude, speed parameters)</td></tr>
<tr><td colspan="2">Monitor navigation (observe heading, crosstrack, distance remaining, ground speed, calculate time status, read diagram, ensure terrain clearance)</td></tr>
<tr><td colspan="2">Listen (radios and aircrew inputs)</td></tr>
<tr><td colspan="2">*Monitor formation position (observe position parameters, closure velocity and pursuit curve)</td></tr>
<tr><td colspan="2">Scan for threats (look outside**, listen to Radar Warning Receiver)</td></tr>
<tr><td colspan="2">***React to threat (call for threat/maneuver)</td></tr>
<tr><td rowspan="2"></td><td>Observe weather radar</td></tr>
<tr><td>Monitor ACAWS/systems advisories</td></tr>
<tr><td rowspan="13">Copilot</td><td colspan="2">Monitor aircraft performance (observe attitude, altitude, speed parameters)</td><td rowspan="13">Copilot</td></tr>
<tr><td colspan="2">Navigate (observe heading, crosstrack, distance remaining, ground speed, calculate time status, read chart, ensure terrain clearance)</td></tr>
<tr><td colspan="2">Listen to radios</td></tr>
<tr><td colspan="2">*Monitor formation position (observe position parameters, calculate closure velocity and pursuit</td></tr>
<tr><td colspan="2">Scan for threats (look outside**, listen to Radar Warning Receiver)</td></tr>
<tr><td colspan="2">***Call for threat/monitor safety of flight</td></tr>
<tr><td colspan="2">***Direct pilot corrections</td></tr>
<tr><td colspan="2">Manipulate SKE settings</td></tr>
<tr><td rowspan="5"></td><td>***Make changes/update navigation system</td></tr>
<tr><td>Observe weather radar</td></tr>
<tr><td>Monitor ACAWS/systems advisories</td></tr>
<tr><td>Read Checklists</td></tr>
<tr><td>***Troubleshoot system malfunctions</td></tr>
<tr><td rowspan="7">Navigator</td><td>Navigate (observe heading, crosstrack, distance remaining, ground speed, calculate time status, read chart, ensure terrain clearance)</td><td></td><td></td></tr>
<tr><td>***Make changes/update navigation system</td><td></td><td></td></tr>
<tr><td>Observe weather radar</td><td></td><td></td></tr>
<tr><td>Listen to radios</td><td></td><td></td></tr>
<tr><td>***Direct Pilot corrections</td><td></td><td></td></tr>
<tr><td>Scan for threats (look outside**, listen to RWR)</td><td></td><td></td></tr>
<tr><td>***Call for threat/monitor safety of flight</td><td></td><td></td></tr>
<tr><td rowspan="7">Engineer</td><td>Monitor aircraft performance (observe attitude, altitude, speed parameters)</td><td></td><td></td></tr>
<tr><td>Monitor systems health (engine, props, electrical, fuel, hydraulics, pressurization, etc)</td><td></td><td></td></tr>
<tr><td>***Troubleshoot system malfunctions</td><td></td><td></td></tr>
<tr><td>**Scan for threats (look outside)</td><td></td><td></td></tr>
<tr><td>***Call for threat/monitor safety of flight</td><td></td><td></td></tr>
<tr><td>***Direct pilot corrections</td><td></td><td></td></tr>
<tr><td>Read checklists</td><td></td><td></td></tr>
</table>

Key
*Formation Only
**Applicable in Visual Meterological Conditions (VMC) only
***Applicable only as needed

Tasks assigned to internal actors have task durations and workload values because they are of primary interest to the analysis. External actors, such as the Loadmaster, Air Traffic Control, Drop Zone Controller, and Formation Lead aircraft are only modeled to show interactions and control the release conditions of tasks assigned to internal actors. External actor tasks do not have a workload value and only have task durations where necessary. Internal actors each have a programmed workload threshold. Their capacity for work can further be modified through IMPRINT by adding environmental stressors such as heat, cold, chemical warfare gear, and night vision goggles, however these modifications are beyond the scope of the current research effort.

A separate Operations Model was constructed for each scenario and as a test bed for basic aircraft control. A model begins with a “START” task and ends with a model “END” task. When a simulation runs, an entity is created and flows through the task network until it reaches the model end node. In order to control large quantities of tasks, IMPRINT allows the modeler to nest subtasks into a larger function. Each function has its own start and end nodes. For both scenarios, each checklist was modeled as a separate function. Some complex task series, such as formation turns and descents, basic aircraft control and checklist steps with sub-tasks, are modeled as their own functions or sub-functions. Each major function for both aircraft and both scenarios are found in Appendix F: IMPRINT Task Networks.

A task begins when any entity reaches the task and a release condition is satisfied. This release condition is defaulted to start the task as soon as an entity reaches it, but it can be programmed in C# code. This C# code can release a task based on simulation clock time, Boolean logic, or other programmable variables. Because any entity can start

the task as soon as the release condition is true, a task can be performed multiple times or simultaneously with other tasks.

As a task is released, it has beginning and ending effects defined in C#, time distribution, workload values, and decision paths. The task duration can be expressed as a constant number, C# expression, or one of many possible distribution functions. To aid the programmer, IMPRINT also provides “micromodels” or algorithms of sample task durations for very simple task (i.e. look at item inside a field of view or read a set number of words). The micromodel can then be used to stitch together multiple motor and cognitive actions and applied to time distribution. Most task durations in this analysis are calculated using rectangular distributions using the micromodel-provided time as the mean value and an estimated range. Once a task is released, the beginning conditions are applied, the task duration is then executed, and finally any ending conditions are run.

After a task is completed it uses a decision path to lead to another task. These decision paths can be a single path, multiple (parallel) paths, tactical, or decision paths. A single path simply moves entities from the current task to the next one. Multiple paths split the entity into parallel processes. Tactical decisions release the entity to any of several follow-on tasks based on Boolean logic. Probabilistic decisions route the entity to one of several tasks based on a user-defined probabilities. However, in order to control the amount of entities flowing through the model, not all tasks included an exit path. Entry pathways and release conditions were coded such that critical path tasks only ran once (and when all pre-requisite conditions were met) and all repetitive tasks run an appropriate number of times.

The task network must be carefully controlled so that each operator only performs a reasonable number of tasks (generally 3 or less) at any given time. Thus, the task network is structured to show the operator cycling between several tasks instead of performing them all in parallel. For instance, to fly the aircraft, the Pilot must monitor several performance parameters, listen to the radio, and operate the throttles and flight controls. Instead of having the Pilot scan all his instruments simultaneously, each instrument is scanned individually in a cycle with more viewing time devoted to more important instruments. This greatly reduces repetitive tasks involved with basic aircraft control.

Each task performed by an internal actor (Pilot, Copilot, Navigator or Engineer) requires a task workload value. IMPRINT uses multiple resource theory and the VACP model of workload assignment. These mental resources are divided into seven channels: visual, auditory, cognitive, tactile, fine motor, gross motor, and speech. The assignment of resource channels is handled through the use of resource-interface pairs. Resources are VACP-resource channels while interfaces are user-defined areas of the cockpit. A given interface can utilize multiple resource channels and the modeler can assign any number of resource channels to a given interface (Figure 7).

Interfaces	Resources						
	Auditory	Cognitive	Fine Motor	Gross Motor	Speech	Tactile	Visual
Control Yoke	☑	☑	☑	☐	☑	☐	☐
CrewStation	☐	☑	☑	☐	☐	☐	☑
ngine Instrumen	☐	☑	☐	☐	☐	☐	☑
nstrument Pane	☑	☑	☑	☐	☐	☐	☑
Intercom/Radio	☑	☑	☑	☐	☑	☐	☐
Nav station	☑	☑	☑	☐	☐	☐	☑
Overhead panel	☐	☑	☑	☐	☐	☐	☑
Rudders	☑	☑	☑	☐	☐	☐	☐
SCNS	☐	☑	☑	☐	☐	☐	☑
Side Panel	☐	☑	☑	☐	☐	☑	☑
Throttles	☑	☑	☑	☐	☐	☐	☐
Window	☐	☑	☐	☐	☐	☐	☑

Figure 7: RI Pairing for C-130H

The interfaces programmed for this analysis break down separate physical areas that are either not in the same field of view or are manipulated differently. A brief explanation of each interface follows:

Control Yoke: operated by the Pilot's left hand or the Copilot's right hand. It is used for pitch and roll inputs and radio/intercom transmissions from the pilots.

CrewStation: generic IMPRINT interface. This is used for tasks that do not fit neatly into one of the other interfaces such as note-taking, map reading, checklist usage, etc. Sometimes this interface is used to simulate the center pedestal.

Engine Instruments: center engine instrument stack on C-130H or on one of the C-130J multifunction displays. It is used by the Pilot, Copilot, and Engineer (C-130H only).

- Instrument Panel: Flight instruments located directly in front of the operator's seat.
- Intercom/Radio: Operator's microphone, headphones, and microphone switch. Since the pilots have microphone switch on the Control Yoke, their R-I pairing is split between the Control Yoke and Intercom/Radio. Note: the Engineer and Navigator (C-130H only) have pushbutton switches on their intercom cord and foot switches located in the floor.

- Nav Station: Primary interface for the Navigator (C-130H only) that cannot be reached by any other operator.

- Overhead Panel: panel mounted directly over the heads of the Pilot, Copilot and Engineer. Operated by the Engineer on the C-130H and the pilots on the C-130J.

- Rudders: floor-mounted panels operated by the pilots' feet to control yaw.

- SCNS: represent the navigation computer on the C-130H or the CNI-MU on the C-130J.

- Side Panel: represents all switches, circuit breakers, and indicators on the Pilot's left side or Copilot's right side. Also represents the SKE control panel on the C-130H.

- Throttles: operated by the Pilot's right hand or Copilot's left hand.

- Window: represents all tasks involving looking out of the cockpit windows or the C-130J Heads Up Display.

Consistent with Wickens' multiple resource theory, IMPRINT takes the resource-interface pairing assigned to each task and determines if a conflict in channels occurs when the simulation is run. IMPRINT can output a report that shows which channels conflict when, how many times, and a value showing the intensity of the conflict. This conflict value assigned by IMPRINT adds a workload penalty, which may induce a workload strategy.

Finally, as each scenario is constructed, the task flow is reviewed against the checklists, technical orders, regulations, and tactics that created the initial task analysis. For many task sequences, there are multiple ways in which a task is prompted or released in the real world: a proactive operator, a checklist reminder, or audible cue from the radio, aircraft, or other operator. The simulation is run to identify timing problems (i.e. tasks released prematurely or not at all), and eliminate instances where tasks are run too many times.

Perhaps the most significant challenge in ensuring a valid model involved assigning time durations to each task. The micromodels help calculate time involved in looking or pushing a button, but less precise actions, such as verbal responses, calculations, and radio calls could only be approximated reasonably. Most tasks used a rectangular distribution to capture a range of possible task times to be sampled randomly by the simulation. However, the model could not easily demonstrate random hesitation between task completion and the release of the next task. Scenario delays, such as aircraft transit time to a geographic point, could be expressed mathematically, but non-overloaded human operators are assumed to initiate the next task as soon as the previous task is complete and release conditions satisfied. This works reasonably well for completing steps in a checklist, but less so for checklist initiation and briefings (which may be completed prior to initiating a checklist or in the course of accomplishing the checklist). In those instances, a random delay variable was built into the release conditions to allow task initiation within a reasonable time window. While the author's own experience flying similar missions provides the bulk of subject matter expertise, other C-130 aviators were consulted to validate the procedures that constitute the task network.

Phase III: Perform Simulated Experiments

The IMPRINT experiments are designed to answer the investigative questions from Chapter 1, namely measuring workload and situation awareness (SA). The experimental design is a 2x2 factorial design, with the independent variables consisting of the two scenarios and two cockpit configurations (aircraft). The scenario dictates

profile parameters (altitudes, distances, and turns) as well as checklists used (landing verses airdrop checklists). Automation usage is dependent on the aircraft being used (C-130J using more automation than the C-130H) and on the scenario. Workload values depend on the task network, which is directly dependent on both scenario and cockpit configuration. SA is dependent on workload and the activities in the task network. By directly comparing the C-130H and C-130J in the same scenario, then using the IMPRINT workload output, we can measure how automation affects workload during SKE formation airdrop and airland missions (investigative question #1 and 3). Using the novel SA algorithm (described below) to calculate SA in the simulation we can answer IQ #2 and 4: How does automation affect aircrew situation awareness (SA) during SKE formation airdrop/airland missions?

The first scenario is a SKE formation to a personnel airdrop (Formation Airdrop), and the second scenario is a single-aircraft airland to a landing zone (LZ) using maximum effort procedures (Airland). Each of these scenarios are classic examples of typical C-130 training or combat missions. While each scenario involves a different task network, each shares a common set of assumptions and variables. Each scenario (Formation Airdrop and Airland) has a different task network, the timing and quantity of task varies and thus the distribution of workload varies. The C-130H and C-130J have different cockpits: each with different cockpit configurations, operators (namely, the Navigator and Engineer on C-130H), and task networks associated. While the C-130H relies on the cockpit crew of four (Pilot, Copilot, Navigator, Engineer), the C-130J has a cockpit crew of two (Pilot and Copilot). This shifts several tasks to the pilots and to the automation while also eliminating or adding tasks. As a result, the C-130J relies on automated

features such as the Heads'-Up Display (HUD) and autopilot-coupled formation station keeping.

It is important to note that while in operational practice, it is common for Pilot and Copilot to share responsibilities and trade tasks according to who is flying the aircraft (pilot flying versus pilot not flying), it becomes increasingly complex to merge and shift tasks between duties explicitly assigned to the Pilot and Copilot and assumed tasks based on which pilot is flying. For simplicity, the Pilot is always flying the aircraft or directly monitoring the autopilot while the Copilot always performs pilot not flying duties.

The Air Force treats each airplane as a separate Mission Design Series (MDS), and has subsequently developed checklists, tactics, techniques, and procedures in separate publications from the C-130H. Thus, while the overall employment of the aircraft remains similar in concept, the flow and allocation of tasks are dramatically different and must be programmed into IMPRINT as such. Table 6 (see previous) describes the allocation of tasks for the parallel function of basic aircraft control. Many tasks are automated and therefore not directly performed by either operator in the C-130J. Generally speaking, the C-130J Copilot (by the virtue of being pilot not flying) assumes most of the tasks from the C-130H Navigator, while the aircraft automation assumes most of the Engineer's tasks.

Because of the ability to employ automation in the scenario, certain tasks shift from the operator to the automation, thus varying the workload distribution. Attention spent on tasks can have a positive, negative, or neutral impact on situation awareness (SA), particularly attention devoted to information gathering tasks. High workload can

also have an impact on SA, thus SA is dependent on total workload and the tasks themselves.

Some universal assumptions had to be made to limit variables in the scenario. While IMPRINT allows the modeler to incorporate workload strategies based on overload thresholds, this investigation deliberately excludes the use of this feature. Since the experiment is focused on the impacts of workload caused by different cockpit designs, workload strategies will mask overload and near-overload conditions. This ensures that time-dependent task demands manifest themselves as clearly as possible without the human's ability to adapt to maintain a high level of performance. It is of more interest to show where workload peaks occur, and the magnitude of those peaks, even if the total experienced workload is impossibly high. Thus, the reader can clearly identify where workload management strategies must be employed and procedural or engineering changes need to be made. To summarize, the following initial assumptions were made:

- Operator workload thresholds initially fixed at 60 units
- All operators share an equal capacity for work
- No workload strategies will be employed by any operator
- Channel conflicts not included
- For the vast majority of tasks, no degree of hesitation to release and start a task, provided requisite release conditions (if any) are met
- The Pilot is always flying (or monitoring the autopilot), while the Copilot is always performing pilot not flying duties
- Operators do not commit errors, therefore all initiated tasks have a 100% chance of successful completion

Basic Aircraft Control Model

The Basic Aircraft Control function was written separately from either baseline scenario. This was to ease compiling and troubleshooting since many sub functions repeated multiple times during a simulation run. The Basic Aircraft Control function was also the most difficult to contain the number of entities to a reasonable quantity (i.e. prevent the operator from performing an impractical or impossible number of tasks simultaneously). The Basic Aircraft Control Function contains all of the repetitive, ongoing tasks that the crew performs while in flight: manually flying the aircraft, monitoring performance, navigation, monitoring formation position, monitoring aircraft systems, scanning for threats, and listening to radios (Figure 8, Figure 9). When the simulation starts, the sub-functions "Listen to Radios" and "Scan for Threats" run independently and loop internally until the simulation is halted or the aircraft is on the ground.

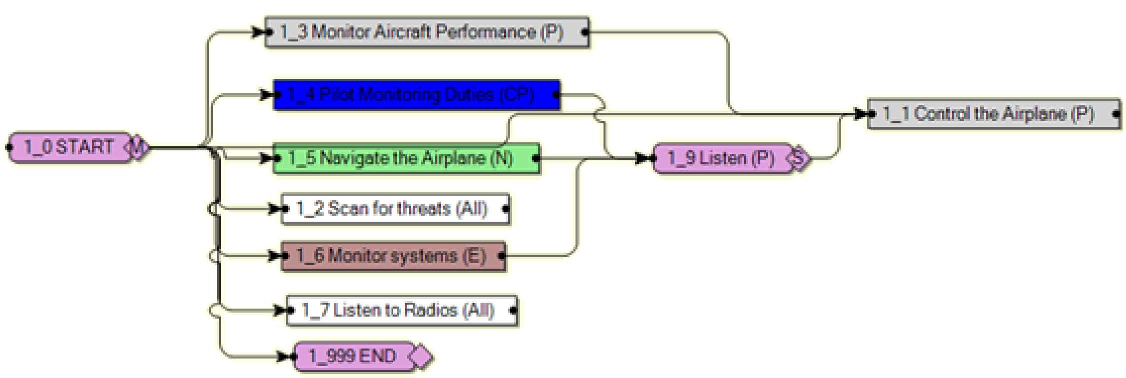

Figure 8: Basic Aircraft Control (C-130H)

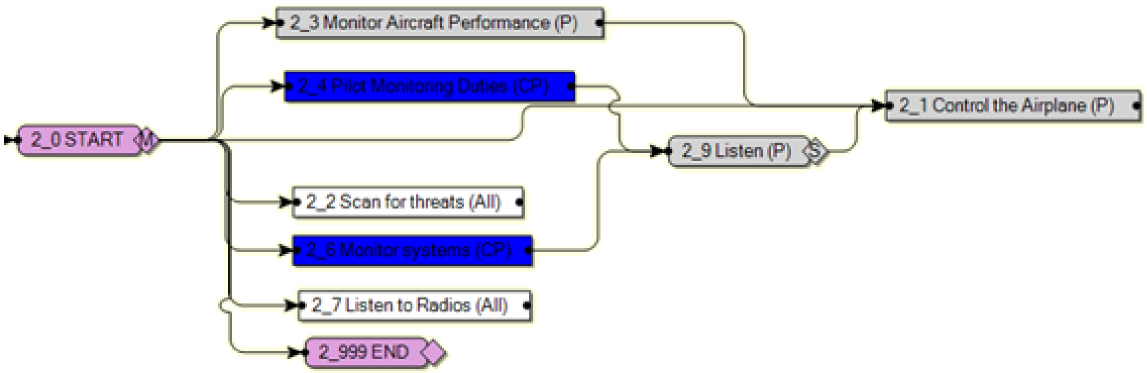

Figure 9: Basic Aircraft Control (C-130J)

All operators begin the simulation performing their respective monitoring tasks. Each operator will continuously monitor an instrument for a short time, then loop back to a routing task to monitor a different instrument. If observed aircraft performance is outside of an arbitrary tolerance (the tolerance itself is arbitrary because an operator's threshold for correcting performance is variable depending on the situation and team), then that operator executes a correction task, which necessitates an active response from the pilot in the Control the Airplane function. Thus the Pilot is reacting to feedback given by the crew and his own observed performance feedback. Since not each performance measure is observed an identical number of times (i.e. the Pilot will observe altitude, attitude, and heading more than chart reading), the routing tasks assign a probabilistic decision path according to perceived level of importance to that operator. Probabilistic decision paths are also used to determine the number of corrections given to the pilot versus making no correction (the "Do Nothing" task).

Some adaptability was built into the Basic Aircraft Control function. If the formation variable is false, then the sub-functions for monitoring and controlling formation position were deactivated. The automation variable controls whether most

monitoring, correcting, and controlling tasks need to be performed. If the aircraft is flying in adverse weather (instrument meteorological conditions), the aircrew cannot see out of the window, then they are not tasked to visually scan for threats. Presence of weather and altitude dictate how much, if any, time is spent examining the radar or performing terrain avoidance tasks (such as chart reading and visually clearing terrain through the window). Finally, the whole function will halt when the aircraft is no longer flying (i.e. landing and ground operations in the Maximum Effort Airland scenario). The combination of variables provides necessary flexibility to work in both scenarios and several alternative variations.

Scenario 1: Formation SKE Airdrop

The first mission scenario chosen is a formation personnel airdrop using Station Keeping Equipment (SKE). This scenario models an aircrew as an element leader (i.e. the third aircraft) in a multi-aircraft formation. Thus the aircrew must maintain a formation position and also relay commands to following aircraft. SKE Formation captures several differences between the C-130H and C-130J: manual versus automatic formation commands, manual aircraft control versus autopilot, navigation systems, and information presentation. Most of these differences are from the C-130J's use of the Coordinated Aircraft Positioning System (CAPS) in conjunction with SKE. In the baseline version of this scenario, the C-130H Pilot manually flies the aircraft and the Navigator performs required radar updates. The C-130J Pilot monitors CAPS maintain SKE position and the computer performs an automatic drop.

The scenario begins 20 minutes prior to the airdrop with the formation at an enroute altitude of 11,000 feet and airspeed of 200 knots (Figure 10, Figure 11). The formation must descend to 3000 feet and turn at the initial point (IP). During this first portion, the aircrew is executing the Preslowdown Checklist. Then, the formation slows from enroute airspeed to drop airspeed of 130 knots and descends to 2000 feet while the aircrew completes the Slowdown Checklist. When the aircraft crosses the drop zone (DZ), the Pilot must maintain a constant heading and a stable formation position as the paratroopers jump out of the aircraft and the Release Point checklist is run. At the end of the DZ, the aircrew runs Completion of Drop Checklist, and the formation climbs away and turns to an escape heading. A detailed narrative describing the SKE Formation scenario is found in Appendix B: Detailed Scenario Narratives.

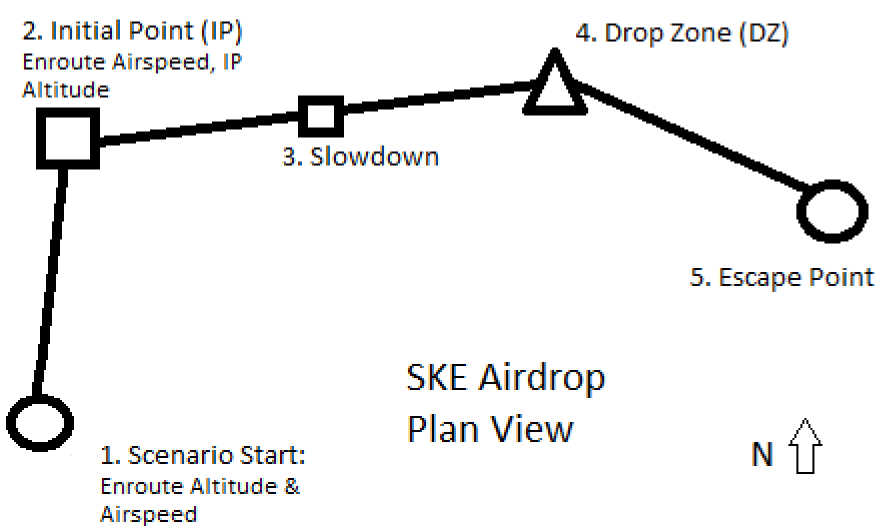

Figure 10: SKE Formation Airdrop scenario Plan View

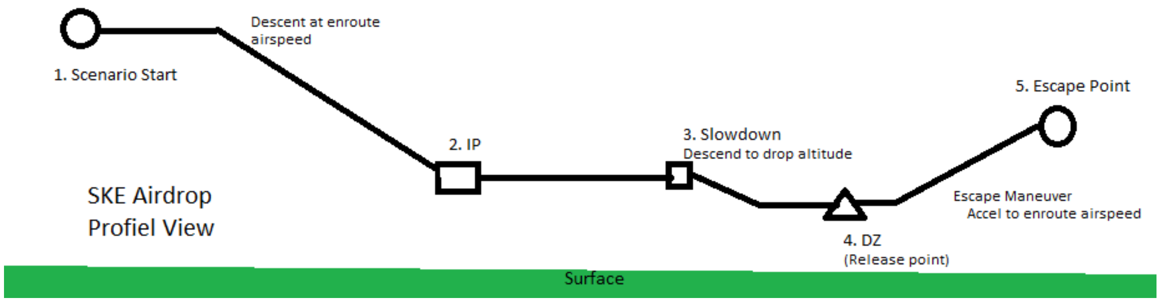

Figure 11: SKE Formation Airdrop scenario Profile View

Scenario 2: Single Aircraft Tactical Arrival/Maximum Effort Airland

This scenario features a penetration descent: a steep, high-speed descent profiles with minimum slowdown distances and steep final approaches into the landing zone (LZ). The penetration descent requires precise obstacle awareness and is difficult to assess and correct energy deviations (AFTTP 3-3.C-130J, 2010; AFTTP 3-3.C-130E/H, 2010). The C-130J and C-130H have different tools to evaluate energy state and progress along this profile but construct them in the same manner. Aircrews construct an energy profile (altitude vs. distance) working backwards from the approach end of the LZ until enroute altitude (Figure 12). This profile consists of a high-speed penetration segment, a level slowdown, and a final approach to landing. While both aircrews must calculate their approach parameters, they monitor performance differently. The C-130J incorporates more sophisticated data through the multifunction display (MFD), moving map, and heads-up display (HUD), the C-130H crew relies more on "eyeballing" out of the window, basic instrumentation, and raw computer data.

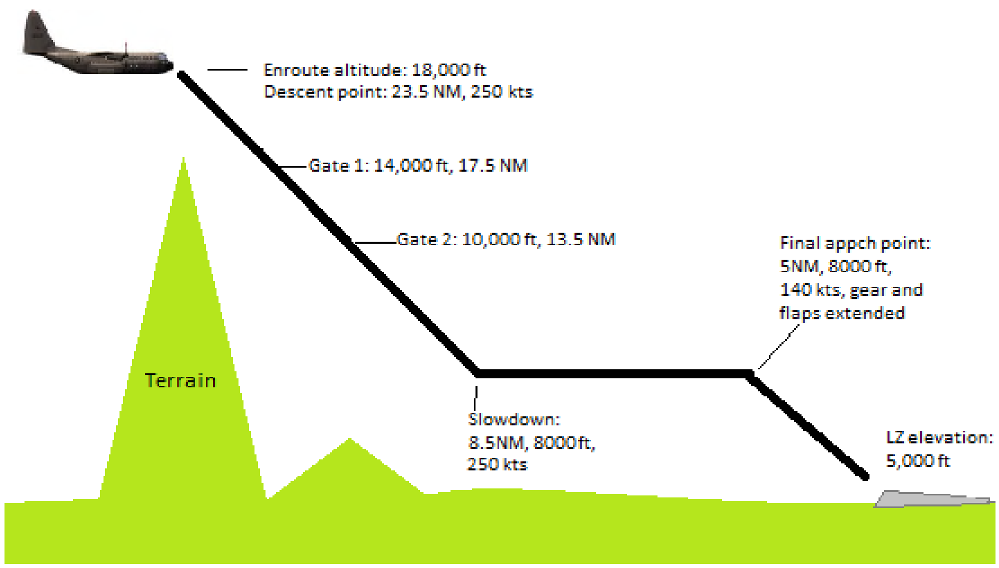

Figure 12: Sample Penetration Descent Profile

The baseline simulation starts at an enroute altitude of 18,000 feet with the autopilot engaged. After computing performance data, the aircrew descends to 6,000 feet, levels-off, then slows down and configures the aircraft for landing. The configuration and final approach phase exploit the different internal crew communications for checklists and advisories, as well as the Pilot's ability to judge touchdown point using the HUD or the window. After landing, the aircraft taxis and parks to conduct an offload. The scenario ends with completion of offload and clearance to taxi.

Measuring Workload and Situation Awareness

Of primary importance to this experiment is the measurement of workload distribution. IMPRINT measures operator experienced workload by computing the combined VACP scores for each task being performed by the operator at that time. As each simulation is run, a time-based workload distribution is computed in table and graphical form. From this output, statistically significant workload peaks can be

identified and measured. The total number of significant peaks, their magnitude and duration, as well as tasks associated with these peaks provide context for why these periods experience high workload. Due to the complexity of the task networks and cycling of basic tasks from the Basic Aircraft Control function, considerable workload noise should be expected to develop in the form of a sine wave. This wave measures the average experienced workload for each operator, and when compared with the workload peaks, conclusions are drawn regarding which aircraft works harder on average and which aircraft is more prone to overload conditions.

Corresponding to Endsley's research (1993) and Figure 5 (from Chapter 2), there exists a real and dependent but dissociate connection between workload and SA. Similar to Plott, Endsley, and Strater's study of predictive SA and human performance modeling (2004), human error is excluded from the model, thus resulting in a best case or optimistic estimation of potential SA. This experiment assumes that some of the operator's available cognitive resources are utilized to gain a strategic awareness of the environment. Thus, available cognitive resources up to a point of overload, represent the potential to gain SA. This potential SA remains high until the operator approaches cognitive overload, which this study is defining as a workload threshold of 60 to be consistent with other IMPRINT studies, including the sample IMPRINT models for the AH-64, CH-47, and UH-60 helicopters (Bierbaum, Szabo, & Aldrich, 1989; Mitchell, 2000; Alion Science, 2013). In this model, SA degrades as workload increases. Note that there is no degradation of SA for an underloaded or bored operator. Potential SA reflects the operator's perception of the environment (Level 1 SA) and is not directly attributed to any specific task in the task network, but rather this strategic SA metric is a

separate task represented by the SA function (Figure 13). This function captures strategic SA acquired from non-scripted attention or SA drawn from stored memory. It is desired that this scoring methodology be compatible with a SAGAT evaluation that could be conducted in a simulator or in-flight experiment, but validation using specific SAGAT questions is beyond the scope of the current effort. Instead, these tasks measure strategic SA generically by attempting to describe the untasked capacity that the operator uses to devote attention to the operator-determined SA priorities at that time.

Figure 13: Strategic Situation Awareness Function

To measure Strategic SA, a separate SA function was created to reflect workload-based SA in three levels: high, medium, and low (Figure 13). The operator will only occupy one of these levels of SA at a time. High SA is when workload is less than 40 (out of 60), Medium SA occurs when workload is between 40 and 45, and Low SA is when workload is between 45 and 50. Above a workload of 50, the operator is close enough to overload that a potential for strategic SA will not register. These workload threshold were chosen based on the workload experienced from the baseline basic aircraft control activities and the IMPRINT default overload threshold of 60 and to mirror the structure of Endsley's SA/Workload function (Figure 5). These SA tasks assign a generic strategic component to the SA variable assigned to each operator. Since SA is both a result and generator of workload, the strategic SA function also induces cognitive workload according to the amount of SA. Using the VACP scoring method, High SA

incurs a cognitive workload score of 6.8 (Evaluation/Judgment considering multiple factors), Medium SA incurs a workload of 4.6 (Evaluation/Judgment considering a single factor), and Low SA incurs a workload of 1.2 (Alternative selection).

In addition to available cognitive resources contributing to strategic SA, specific tasks add to specific elements of SA. These tasks increment the SA of the operator performing them for the time that the task is being performed. To distinguish task-specific SA with generic, strategic SA, these SA values are referred to as “tactical SA.” While it is possible for the operator to retain that SA in short-term memory, to control the SA score, each task is de-incremented after completion, thus emphasizing attention devoted to tasks that increase SA. Theoretically, any tactical SA gained by completing a given task, should become part of the immediate strategic SA once the task is complete. However, modeling the decay rates of tactical SA due to memory loss is beyond the scope of this current research, and thus tactical SA is assumed to end immediately as attention shifts away from the current task contributing to tactical SA. Relevant elements of tactical SA can then be stored as strategic SA.

In order to quantify the relative contributions that each individual task contributes to tactical SA, a survey (Appendix C: Situation Awareness Task Assessment) was sent to 15 aviators representing pilots, navigators, engineers, and special mission aviators in a host of platforms, but with emphasis on past or current C-130 or HUD experience. This survey distilled the 1200+ task nodes in the IMPRINT model into 19 main categories. Respondents were asked to rate the relative impact to SA for accomplishing each task (compared to a baseline of flying with one’s eyes closed) on a scale from -3 to +3, where

negative values detract from SA, zero equals no affect on SA, and positive values contribute to SA. Results of this survey are shown in Table 7.

Table 7: SA Survey Results

Questions/Tasks	Cruise Average	Cruise Std Dev	Formation Airdrop Average	Formation Airdrop Std Dev	Max Effort Airland Average	Max Effort Airland Std Dev
1. Reading instrument or gauge	1.46	0.88	1.60	0.55	1.60	0.55
2. Reading MFD/moving map/digital display	2.23	0.83	2.40	0.55	2.40	0.55
3. Viewing Head's Up Display (HUD)	1.40	0.55	2.00	1.00	2.00	1.00
4. Looking out of window	1.77	1.09	2.00	0.71	2.00	0.71
5. Reading raw computer data	-0.31	1.18	-0.40	1.34	-0.40	1.34
6. Radar/sensor interpretation	1.46	0.78	1.20	1.10	1.20	1.10
7. Keyboard/data entry	-1.08	0.76	-1.20	0.84	-1.20	0.84
8. Writing (data cards, kneeboard, etc.)	-0.31	1.03	-0.40	1.34	-0.40	1.34
9. Reading charts, "sticks," approach plates	1.15	1.07	1.00	0.71	1.00	0.71
10. Manual computations (whiz wheel, TOLD, tab data, etc)	-1.08	1.38	-1.20	1.30	-1.20	1.30
11. Talking, simple (advisory calls, responses)	0.62	0.96	-0.20	0.84	-0.20	0.84
12. Talking, complex (briefings, radio calls, etc)	0.00	1.68	-1.20	1.30	-1.20	1.30
13. Listening, simple (alerts, advisory call)	1.23	0.73	0.40	0.89	0.40	0.89
14. Listening, complex (radio, crew feedback)	1.15	1.21	0.60	1.14	0.60	1.14
15. Background listening (monitoring RWR, radio)	-0.15	1.14	-0.60	1.14	-0.60	1.14
16. Simple maneuvering (maintaining parameters)	0.15	0.80	-0.60	0.55	-0.60	0.55
17. Complex maneuvering (defensive reactions)	-1.31	0.63	-1.80	0.45	-1.80	0.45
18. Simple button/switch actuation	-0.08	0.49	-0.40	0.55	-0.40	0.55
19. Cumbersome button/switch actuation	-1.00	1.08	-1.80	0.84	-1.80	0.84

It is important to note that survey participants were not explicitly briefed on the difference between tactical and strategic SA, however they were asked to disregard the effects of workload on their SA scores. In reporting SA scores, some participants provided negative SA scores, which we hypothesize represents an opportunity cost that most likely trades off tactical and strategic SA. Thus performing task A (tactical task) consumes attentional resources that may have been spent on a hypothetical task B (strategic task) that would have yielded more SA. In reality, a negative tactical SA score would imply that by accomplishing a task, false SA would be gained leading to an incorrect mental model. It is hypothesized that the participants were not suggesting that

any activities were actually contributing to incorrect mental models. These negative values are deliberately not incorporated into the tactical SA scoring because the opportunity costs are already accounted for by decrementing the operator's strategic SA score since those tasks are typically high-workload tasks. Furthermore, several tasks were coded in IMPRINT to pass an "(operator)_busy" variable which would hold the release condition of other SA-gaining tasks (i.e. an Engineer doing performance calculations would not be monitoring systems).

The total SA score is the sum of a strategic SA value plus all of the tactical SA values at that given time. Using a total SA benchmark of 1.0, strategic SA has individual scores from 0.25-0.75. The Low SA task adds 0.25, Medium SA equals 0.5, and High SA equals 0.75. At the completion of each task, the increment assigned (0.25, 0.5, or 0.75) is de-incremented and the function repeats. Because multiple tasks can be performed simultaneously, the tactical SA scoring for individual elements are set lower than strategic SA to balance their effects on total SA. Thus, the highest individual tactical SA score was set equal to 0.25, which is also the lowest strategic SA score. Since decrementing strategic SA accounted for negative scores in the SA survey, the minimum reported tactical SA scores were rounded up to zero. All of the survey results were rounded to the nearest 0.5 and divided by 10 as shown in the adjustment table (Table 8), to achieve individual tactical SA values between 0 and 0.25.

Table 8: IMPRINT Tactical SA Adjustments to SA Survey Results

Raw Average	Tactical SA
if Avg <.25	0.00
if .25 < Avg < .75	0.05
if .75 < Avg < 1.25	0.10
if 1.25 < Avg < 1.75	0.15
if 1.75 < Avg < 2.25	0.20
if 2.25 < Avg	0.25

Applying these scores to the generalized list of 19 tasks allows the assignment of tactical SA values to be used in IMPRINT (Table 9). Some tasks, such as viewing the HUD and looking out of the window, yielded lower values for cruise flight than for the tactical events. Thus, a lower tactical SA value is programmed into IMPRINT when the aircraft is at cruise altitude and a higher tactical SA value when the aircraft is at low altitude or executing tactical events. For an exhaustive list of tactical SA scores assigned to all tasks in each scenario, consult Appendix D: Task Listings and Tactical SA Assignments.

Table 9: IMPRINT Tactical SA Values

Questions/Tasks	Tactical SA Score
1. Reading instrument or gauge	0.15
2. Reading MFD/moving map/digital display	0.25
3. Viewing Head's Up Display (HUD)	.15/.2*
4. Looking out of window	.15/.2*
5. Reading raw computer data	0
6. Radar/sensor interpretation	0.15
7. Keyboard/data entry	0
8. Writing (data cards, kneeboard, etc.)	0
9. Reading charts, "sticks," approach plates	0.1
10. Manual computations (whiz wheel, TOLD, tab data, etc)	0
11. Talking, simple (advisory calls, responses)	0
12. Talking, complex (briefings, radio calls, etc)	0
13. Listening, simple (alerts, advisory call)	0.05
14. Listening, complex (radio, crew feedback)	0.05
15. Background listening (monitoring RWR, radio)	0
16. Simple maneuvering (maintaining parameters)	0
17. Complex maneuvering (defensive reactions)	0
18. Simple button/switch actuation	0
19. Cumbersome button/switch actuation	0

*First value indicates cruise altitude and second value indicates tactical events

By combining the strategic and tactical SA scores, a total SA score for each operator is calculated. The time-distributed value of each operator's SA shows how operator SA changes throughout the scenario in much the same way as the workload distribution described earlier. It is important to note that the SA scores reflect only the potential for Level 1 SA. It is up to the reader to make implications on the effects of higher SA levels, since there is no method to predict comprehension ability through IMPRINT.

Comparing Total SA between aircrews as a whole poses some problems. While individuals maintain SA in their own right, how do we measure the collective SA for the aircrew as a whole? As discussed in the Chapter 2, Team SA is a product of the overlapping SA between individuals. This requires a degree of communication, but also

is affected by each operator's priorities. If all members posses the same information, then there is no net gain in SA. Team SA is not simply the sum of individual SA.

If one were to simply average individual SA scores, then the operator with lower SA would drag down the team score. This does not fully describe the advantage of working in a team setting: specialization and redundancy allows individuals to put together different pieces of information together to form a better mental model. The adage, "one of us is not as smart as all of us," captures this concept. While Team SA may not be perfectly synergistic, perhaps it the advantage in team settings is that one person can fill gaps in SA left by other operators. That is, the team SA at any given point in time is not the sum of individual SA scores, nor is it the average of the individuals, but the value of the individual who has the highest SA at that given moment in time. Therefore the individual contributing most towards team SA changes as the situation evolves. This captures the dynamic nature of SA in team settings, but only the *potential* for team SA. Clearly, if the individual with the highest SA withholds that information from the team, then that benefit is lost.

Figure 14 illustrates this team SA concept versus taking an average of individual SA scores. With three hypothetical operators (A, B, and C), the team's average SA would always be lower than someone's individual Total SA. However, when the Team SA function (heavy black line) uses the highest individual Total SA score at each given moment in time, then different members of that team are contributing towards Team SA.

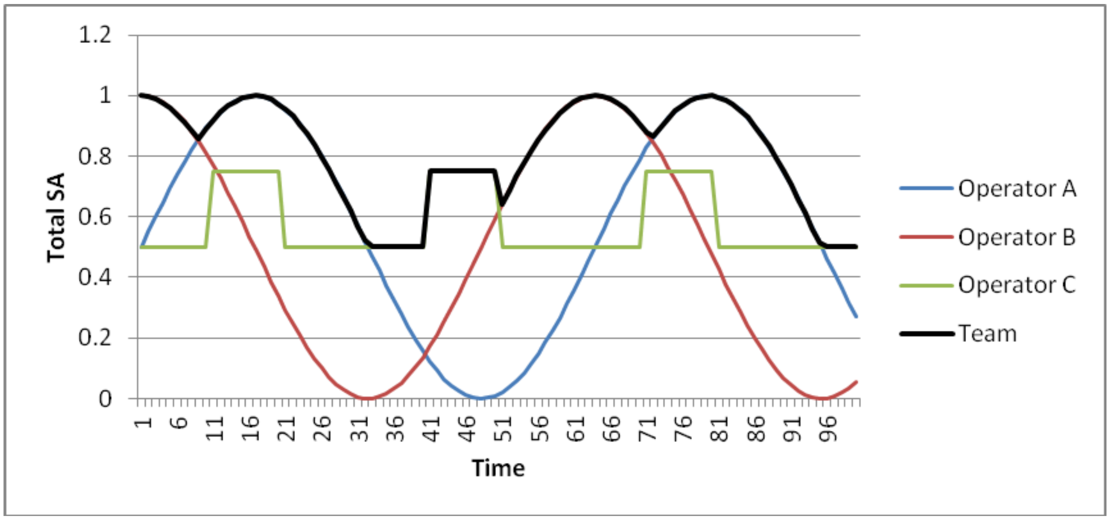

Figure 14: Team SA Example

However, even this method of measuring Team SA is not without drawbacks. Since it only considers the total SA value of the individual with the highest total SA at that instant in time, it discounts the contributions of every other member in that team with lower SA. This ignores contributions and gaps in SA filled by the rest of the team and the complex interaction between team members. By not factoring in the required communication (or lack thereof) between team member, the team SA formula ignores the possibility that an individual with lower SA might make a crucial contribution towards the team as a whole. While not ideal, measuring SA for the group is still a relevant and important metric to capture the effects of removing humans from the cockpit.

Phase IV: Analyze Results

First, one trial run for each of the 4 conditions (C-130H Formation Airdrop, C-130J Formation Airdrop, C-130H Airland, and C-130J Airland) is run. A detailed IMPRINT output allows for careful study of the characteristics for each simulation. The single-iteration output provides graphical identification and qualitative determination of

where significant workload peaks occur that can be quantitatively described. IMPRINT easily outputs large data files of time-based workload values. By running 14 iterations of the model through pair wise *t*-tests and examining the comparing the family-wise error rate to a Bonferroni post hoc test, a comparison of the data and it's statistical significance can be made. These two methods will answer investigative questions #1 and 3: how automation affects workload during SKE formation airdrop and an airland mission. Similarly, charting the time-based distribution of the situation awareness variables, another single iteration qualitative analysis of SA can be made. Measuring total SA over multiple iterations and interpreting through another *t*-test and Bonferroni test answers questions #2 and 4: how automation affects SA during SKE formation airdrop and an airland mission.

Summary

This research employs IMPRINT, a discrete-event simulation human performance modeling tool, to calculate a time-based distribution of workload. Workload distributions are calculated by creating task networks from operating procedures for each aircraft according to SKE formation airdrop and maximum-effort airland scenarios. By creating scenarios for each aircraft, the differences in cockpit configuration (automation, switches, displays, and crew compliment) and scenario events serve as independent variables to show differences in workload. IMPRINT generates the workload profile, which allows the experimenter to observe and measure the timing and duration of workload peaks, which answers the first investigative question. The author has created a situation awareness function to measure workload-dependent degradation of strategic SA under

high workload conditions. When combined with task-specific SA contributions, a total score for potential SA is computed, thus answering the second investigative question regarding the impact of automation on SA.

This experiment distinguishes itself because it focuses heavily on using checklists and operational procedures of the C-130 instead of higher-level observations of C-130 operational practices. It seeks to model the cockpit task network on a very fine level of detail. Predictive methods of determining SA are nascent. By developing a novel method of establishing a generic strategic SA component, which is dependent on experienced workload, and combining that with task-specific "tactical" SA elements, this research seeks to establish an SA measurement that could potentially be evaluated later with other methods such as SAGAT. Finally, the author proposes one method to estimate potential team SA.

IV. Analysis and Results

Chapter Overview

Two scenarios were modeled in IMPRINT: SKE Formation Airdrop and Maximum Effort Airland. For each scenario, IMPRINT models representing both the automated system (C-130J) and non-automated system (C-130H) were run to output workload and situation awareness profiles. Inspecting the results of a single iteration leads to qualitative analysis of overall trend and a more focused analysis of identified workload peaks. Collecting data from multiple iterations and using pair-wise *t*-tests identified the quantitative difference between the C-130H and C-130J. Finally, this analysis is compared to the test hypotheses outlined in Chapter I to answer the original investigative questions.

Results of Simulation Scenarios

Workload Analysis

SKE Formation Airdrop Scenario

Each scenario was run for a single iteration in order to obtain a detailed, continuous IMPRINT workload profile. This is used as the basis for the qualitative analysis. For the C-130H SKE Formation Airdrop Scenario, a level sine wave develops and remains centered on approximately 20 workload units throughout the duration of the workload run (Figure 15). The Engineer's workload sine amplitude of about 3-4 units (centered on 21 units), while the Pilot and Navigator experience the largest sine

amplitude of about 10 units (centered on 19 units). While the workload sine wave remains remarkably consistent, several peaks stand out as significant.

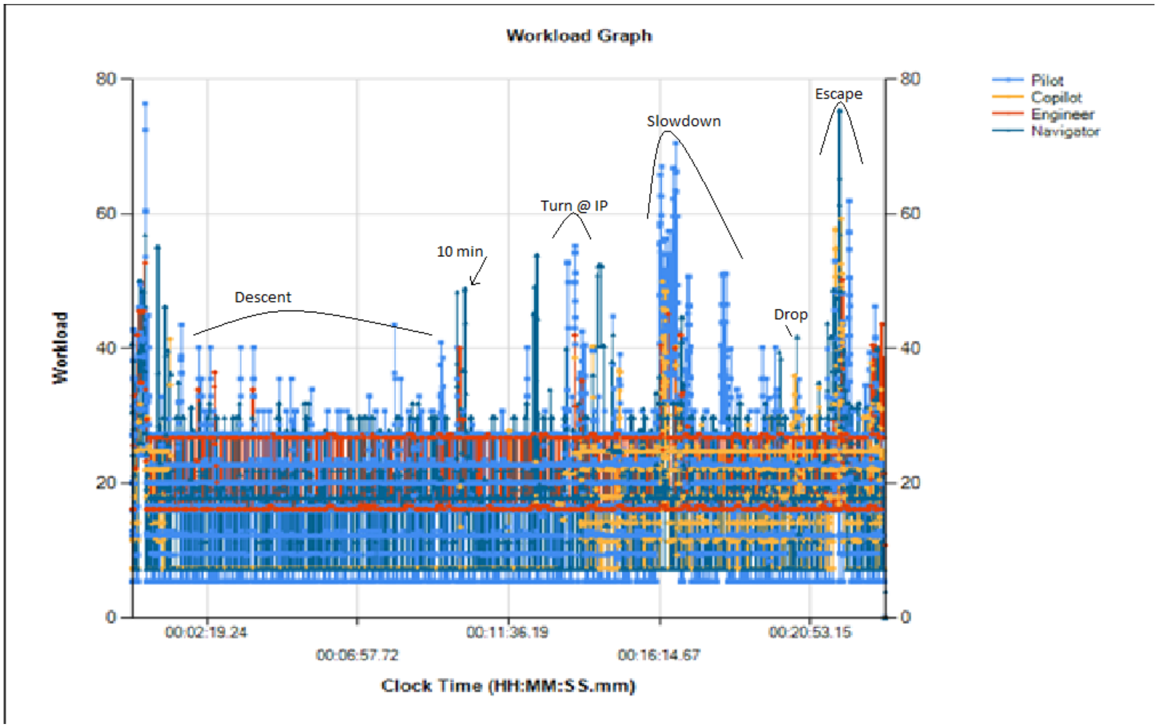

Figure 15: C-130H, SKE Formation Airdrop scenario Workload Distribution

To take a qualitative look at those peaks, all workload values below 40 were omitted and all workload values above 40 were grouped together in similar time brackets (Table 10). Generally, any gap exceeding 30 seconds between any two high workload values was considered as separate peaks. After this grouping, the peak start time (defined as the time where workload exceeded 40 units) and duration (time elapsed from start until workload is less than 40) are identified and compared with corresponding tasks in the Operator Workload Detail output from the IMPRINT simulation run. Note that some of the durations are less than one second, which represents a random instantaneous spike in operator workload.

Table 10: SKE Formation Airdrop Workload Peaks (C-130H)

	Start Time (hh:mm:ss)	Duration (hh:mm:ss.ss)	Max Worload	Phase of Mission
Pilot	00:00:02.42	00:00:27.95	76.4	Preslowdown
	00:01:31.65	0	43.50	Formation Descent
	00:02:03.63	00:00:21.48	40.10	Basic Aircraft Control
	00:08:04.90	0	43.5	Basic Aircraft Control
	00:09:31.02	00:00:30.01	40.9	Formation Descent
	00:12:10.59	0	40.1	Basic Aircraft Control
	00:13:24.55	00:00:32.20	55.2	Formation Turn at IP
	00:14:48.43	0	44.8	IP to DZ Run In
	00:16:14.39	00:02:03.81	70.5	Slowdown
	00:19:24.88	00:00:23.85	40.1	Release Point
	00:21:38.60	00:01:14.54	61.9	DZ Escape
Copilot	00:01:09.93	00:00:00.07	41.4	Preslowdown
	00:14:10.85	0	40.3	Basic Aircraft Control
	00:16:19.24	00:00:25.39	49.9	Slowdown
	00:21:38.99	00:00:13.53	59.3	DZ Escape
Navigator	00:00:00.00	00:01:00.52	56.9	Preslowdown
	00:10:00.71	00:00:15.07	48.9	Preslowdown
	00:12:21.41	00:00:08.59	53.9	Formation Turn at IP
	00:14:19.80	00:00:28.63	52.3	IP to DZ Run In
	00:16:54.30	00:00:01.33	44.7	IP to DZ Run In
	00:20:28.67	0	41.8	Release Point
	00:21:24.42	00:00:24.11	75.4	Release Point
Engineer	00:00:08.46	00:00:15.45	52.7	Preslowdown
	00:13:37.93	00:00:00.61	42	Preslowdown
	00:16:16.72	00:00:35.39	45.1	Slowdown
	00:21:51.29	00:01:13.71	50.2	Escape

Since there was no workload strategy employed during this simulation run, workload was allowed to exceed the IMPRINT default overload threshold of 60 units. All tasks, therefore, were initiated on-time (as soon as release conditions were met). A recurring trend in for each workload peak were common parallel tasks such as: scanning for threats, listening to radios, monitoring aircraft, and flying (Pilot only) tasks. It would be logical to assume that some of these tasks would be prioritized (i.e. flying) and others

suspended based on evolving prioritization (i.e. not scanning for threats when running checklists or at higher altitudes).

Not surprisingly, the Pilot had both the most workload peaks (11 total, 4 of which were momentary spikes), and the highest instantaneous workload value (76.4 units) among the crew. Because the Pilot must manually fly the aircraft, maintain a formation position, and pass commands via the push-button Flight Command Indicator (FCI), workload can elevate easily when other tasks are introduced. Indeed, even the Basic Aircraft Control function occasionally spiked above 40 units when the Pilot mentally evaluated his performance while conducting other parallel tasks. Several significant peaks stand out:

- The highest workload value (76.4) occurred during a 27 second peak at the beginning of the scenario when calling for the Pre-slowdown checklist and executing the checklist while flying at enroute altitude.
- While executing the SKE formation turn and leveling off from the first descent, there are 30-32 second peaks with workload values of 41 and 55. This is due to tasks associated with talking on the radio, sending commands, and increased effort to monitor and evaluate the formation turn.
- The slowdown-drop zone-escape sequence resulted in several long workload peaks (24 seconds to over 2 minutes) in succession with high maximum values (70.5 for slowdown, 40.1 for the drop zone, and 61.9 for the escape maneuver). This sequence best captures the demands of flying the SKE formation airdrop since the Pilot assumes control for FCI commands from slowdown until escape, while making large airspeed changes, configuring the

aircraft, executing checklists, and flying to tighter positional tolerances as the aircraft nears the release point.

The Navigator was the second-busiest operator on the aircrew with 7 workload peaks above 40 units (2 momentary spikes). Surprisingly, approaching the release point, the Navigator only had one momentary workload spike when evaluating drop parameters. The Navigator's two busiest times occurred at the beginning of the simulation (1 minute long, peak of 56.9) while writing data on the drop briefing card, briefing the airdrop and accomplishing the Pre-slowdown checklist, and also completing the drop (24 seconds long, 75.4 maximum workload), directing the escape maneuver and responding to the Completion of Drop checklist. Other notable peaks include the formation turn at the Initial Point (IP) which lasted 9 seconds and peaked at 53.9, and updating computer drop information in the Self Contained Navigation System (SCNS) which lasted 58 seconds and peaked at 52.3. During this run only Navigator and the Pilot experienced overload conditions.

The Copilot and Engineer were considerably less busy. Both experienced four peaks (two and one momentary spikes, respectively). The Copilot's workload peaks occurred while responding to the Slowdown checklist and extending flaps (25 seconds, 49.9 maximum) and again during the escape maneuver while reconfiguring the SKE secondary control panel and responding to the Completion of Drop checklist (13.5 seconds, 59.3 maximum). The Engineer's workload peaks correlated directly with running the Pre-slowdown (15 seconds, 52.7 maximum), Slowdown (35 seconds, 45.1 maximum) and Completion of Drop checklists (1 minute 14 seconds, 50.2 maximum).

The C-130J iteration of the SKE Formation Airdrop scenario, with its improved automation, glass cockpit, head's-up display (HUD), and reduced crew compliment (the Navigator and Engineer have been replaced with automation), has the aircraft flying on autopilot and autothrottles until the aircraft was at drop altitude. Then, the Pilot maintained formation position until the escape maneuver was nearly completed, where the autopilot was re-engaged. Because the crew is much smaller, fewer advisory calls and intra-cockpit communication occurred. The C-130J SKE automatically relayed most FCI commands with little to no input from either Pilot or Copilot. Finally increased automation reduced the volume of checklist tasks to a handful of items, along with the associated call-and-response found heavily in the C-130H checklist. As a result, the C-130J exhibited a linear sine wave centered between approximately 17 and 18 units and amplitudes of around 4 units, both lower in average and amplitude than the C-130H (Figure 16).

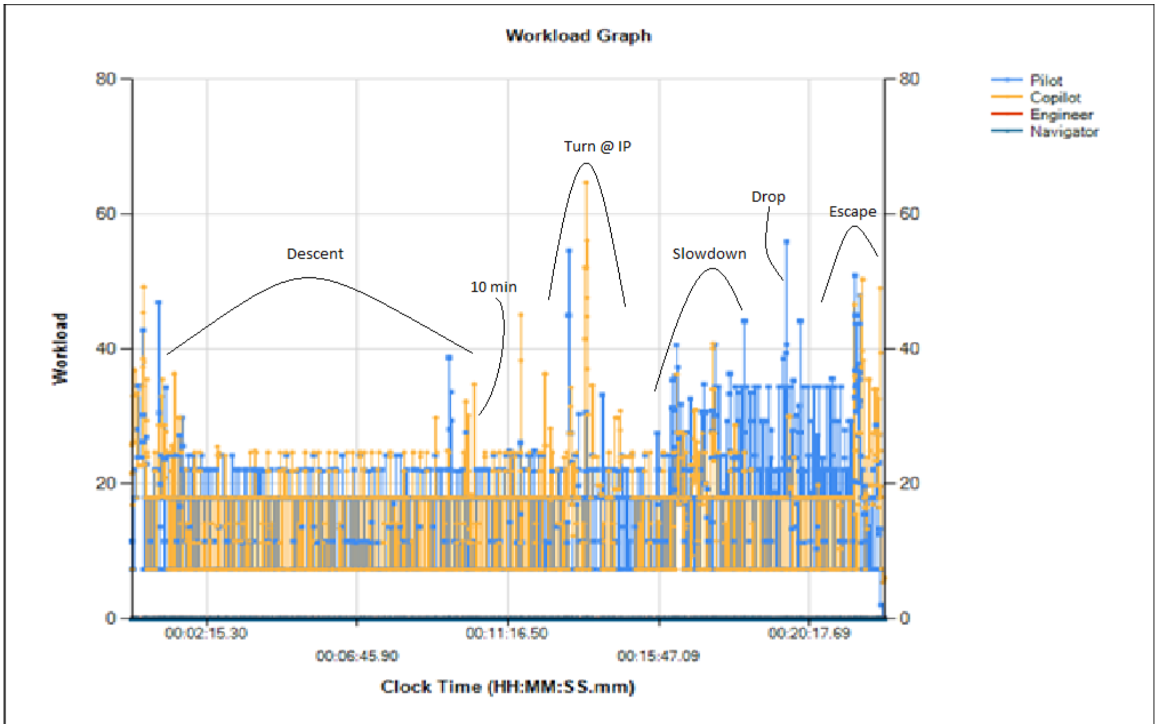

Figure 16: C-130J SKE Formation Airdrop scenario Workload Distribution

Viewing Figure 16, one can identify when the Pilot reverted to a lower level of automation (i.e. increased manual control) when the aircraft was established at drop altitude (approximately 00:17:00.00). While the sine wave is centered at a lower average than the C-130H model, a cutoff of 40 units is still useful to remain consistent with the C-130H analysis and to mitigate noise for the qualitative analysis (Table 11). Notably, the magnitude and quantity of workload peaks decreased from the C-130H simulation.

Table 11: SKE Formation Airdrop scenario Workload Peaks (C-130J)

	Start Time (hh:mm:ss)	Duration (hh:mm:ss.ss)	Max Worload	Phase of Mission
Pilot	00:00:20.16	00:00:27.82	46.9	Drop Preparation
	00:13:04.85	00:00:01.11	54.6	Formation Turn at IP
	00:16:18.56	00:00:00.47	40.6	Slowdown
	00:17:28.27	0	40.7	Slowdown
	00:18:20.74	0	44.1	Slowdown
	00:19:36.71	00:00:24.07	55.9	Release Point
	00:21:39.25	00:00:09.62	50.9	Escape
Copilot	00:00:20.81	00:00:00.58	49.2	Drop Preparation
	00:11:39.27	0	45.1	Basic Aircraft Control
	00:13:33.70	00:00:04.32	64.7	IP to DZ run in
	00:17:23.86	00:00:00.33	40.8	Slowdown
	00:21:38.32	00:00:45.62	50.3	Escape

The Pilot experiences 7 workload peaks, of which only 3 are sustained much longer than one second (compared to the C-130H Pilot who had 11 peaks, of which 7 were sustained). These sustained peaks occurred while responding to the Drop Preparation (28 seconds, 46.9 maximum), executing the airdrop at the Release Point (24 seconds, 55.9 maximum) and Completion of Drop checklists (10 seconds, 50.9 maximum). Nearing the release point, the Pilot experienced a 24 second peak with a 55.9 unit maximum, which is of the same duration but higher than the C-130H Pilot's peak near the release point (24 seconds, 40.1 maximum). However, the C-130J Pilot does not experience the same degree of workload in the final minutes leading to the drop, nor the overload during the escape maneuver. Of note, the formation turn at the Initial Point (IP) spikes briefly, but at 54.6 units, is nearly of same intensity as the C-130H Pilot's workload during the formation turn (32 seconds, 55.2 maximum).

The C-130J Copilot, however, had somewhat similar workload peaks to his C-130H counterpart (5 peaks vs. 4 peaks, both with 2 sustained peaks). However the C-130J

Copilot only experienced sustained workload peaks while copying drop zone winds during the IP-inbound leg (4 seconds, 64.7 maximum) but was overloaded when attempting to listen, write, and perform Copilot duties. The other sustained peak occurred during the escape maneuver (46 seconds, 50.3 maximum) while listening and recording drop scores and executing the Completion of Drop checklist.

Summarizing the single-iteration analysis, the C-130J Pilot experiences a significant drop in quantity, magnitude, and duration of workload peaks, while the C-130J Copilot experiences a slight increase in quantity, magnitude and duration of experienced peaks (Table 12). When the Navigator and Engineer are averaged in, the C-130J crew experiences a slight reduction in quantity and magnitude but a noticeable decrease in duration when high workload is encountered.

Table 12: Summary of Workload Peaks, SKE Formation Airdrop scenario

	# of Peaks	Total Duration	Avg Duration	Avg Workload	Max Workload
H Pilot	11	05:33.8	00:30.3	48.47	76.4
H Copilot	4	00:39.0	00:09.7	47.13	59.3
H Aircrew	6.5	02:39.1	00:24.5	47.91	50.45
J Pilot	7	01:03.1	00:09.0	45.73	55.9
J Copilot	5	00:50.8	00:10.2	48.52	64.7
J Aircrew	6	00:57.0	00:09.5	47.12	48.65

After running 14 iterations of the SKE Formation Airdrop scenario, statistical analysis can determine which aircrew sustains higher average levels of workload (Table 13) and higher maximum workload (Table 14).

Table 13: SKE Formation Airdrop Average Workloads

	C-130H Average Workloads					C-130J Average Workloads		
Iteration	H Navigator	H Engineer	H Pilot	H Copilot	H Aircrew	J Pilot	J Copilot	J Aircrew
1	19.19	22.97	19.02	17.95	19.78	17.17	17.93	17.55
2	19.92	22.89	19.32	18.44	20.14	17.10	17.51	17.30
3	18.96	22.74	19.32	18.22	19.81	17.55	17.10	17.33
4	20.03	23.02	19.06	18.29	20.10	17.24	17.09	17.17
5	19.16	22.59	18.98	18.06	19.70	17.36	17.68	17.52
6	19.80	22.96	19.28	18.30	20.09	17.26	17.21	17.23
7	19.62	23.13	19.14	18.21	20.03	16.90	17.60	17.25
8	19.35	23.07	19.02	18.72	20.04	17.35	17.43	17.39
9	19.81	23.09	19.23	18.17	20.08	17.57	16.91	17.24
10	19.50	23.18	19.54	18.18	20.10	17.26	17.11	17.18
11	18.81	22.75	19.00	18.24	19.70	17.43	16.61	17.02
12	19.15	22.96	19.29	18.37	19.94	17.26	17.09	17.17
13	18.87	23.03	19.30	18.51	19.93	17.00	17.85	17.42
14	18.79	22.85	19.15	18.25	19.76	17.44	16.78	17.11
Averages	**19.35**	**22.95**	**19.19**	**18.28**	**19.94**	**17.28**	**17.28**	**17.28**

Table 14: SKE Formation Airdrop Maximum Workloads

	C-130H Maximum Workloads					C-130J Maximum Workloads		
Iteration	H Navigator	H Engineer	H Pilot	H Copilot	H Aircrew	J Pilot	J Copilot	J Aircrew
1	67.80	49.70	89.50	57.80	66.20	59.90	64.70	41.53
2	70.90	49.70	83.80	68.30	68.18	57.60	64.70	40.77
3	69.70	45.80	83.80	57.70	64.25	54.80	67.90	40.90
4	83.90	49.70	70.50	59.30	65.85	54.60	64.70	39.77
5	67.70	45.50	79.2	68.30	65.18	58.60	64.70	41.10
6	76.70	49.70	79.20	57.50	65.78	54.60	64.70	39.77
7	68.80	49.70	77.50	68.30	66.08	54.60	64.70	39.77
8	75.50	49.70	81.30	75.10	70.40	54.80	58.10	37.63
9	77.60	49.70	81.30	57.70	66.58	61.60	54.10	38.57
10	79.10	49.70	81.30	75.10	71.30	54.80	55.50	36.77
11	77.60	49.70	79.60	61.50	67.10	58.80	64.70	41.17
12	67.00	53.10	79.60	57.50	64.30	54.60	64.70	39.77
13	72.00	53.10	79.20	59.30	65.90	53.40	64.70	39.37
14	77.60	50.20	72.40	57.70	64.48	53.40	64.70	39.37
Averages	**73.71**	**49.64**	**79.87**	**62.94**	**66.54**	**56.15**	**63.04**	**39.73**

Conducting a *t*-test of these data shows that there exists a statistically significant difference within a 95% confidence interval ($\alpha = 0.05$) between the C-130H and C-130J

for average workloads. Data that satisfies the *t*-test also meets the stricter significance criteria of the Bonferroni post hoc test to account for the family-wise error rate (m = 3, $\alpha_{\text{Bonferroni}}$ = 0.017). Examining the difference in averages from Table 13, the C-130J clearly has lower average workload for the Pilot, Copilot and aircrew as a whole (includes Navigator and Engineer) while performing SKE Formation Airdrop. Examining the maximum workload values, the C-130J Pilot and aircrew sustain lower maximum workload than the C-130H, but there is no statistically significant difference between the Copilots. Thus, while average workload results are clear, the maximum workload results for SKE formation airdrop are mixed, but increased automation does not do worse in this scenario.

Table 15: T-test results for SKE Formation Airdrop Workload data

	Average Workload			Maximum Workload		
α=0.05	**Pilot**	**Copilot**	**Aircrew**	**Pilot**	**Copilot**	**Aircrew**
***p*- value**	<0.001	<0.001	<0.001	<0.001	0.966	<0.001
Lower Workload	J	J	J	J	Neither	J

Maximum Effort Airland Scenario

Similar to SKE Formation Airdrop, the first iteration of the Maximum Effort Airland scenario was run for a single iteration with the detailed IMPRINT output for a qualitative analysis. While the SKE Formation airdrop workload approximated a linear sine wave, the Airland scenario data in Figure 17 more closely resembles a bell curve with considerable oscillation superimposed on it. All C-130H operators peaks during the slowdown and final approach phase and diminish rapidly after touchdown and during the cargo offload.

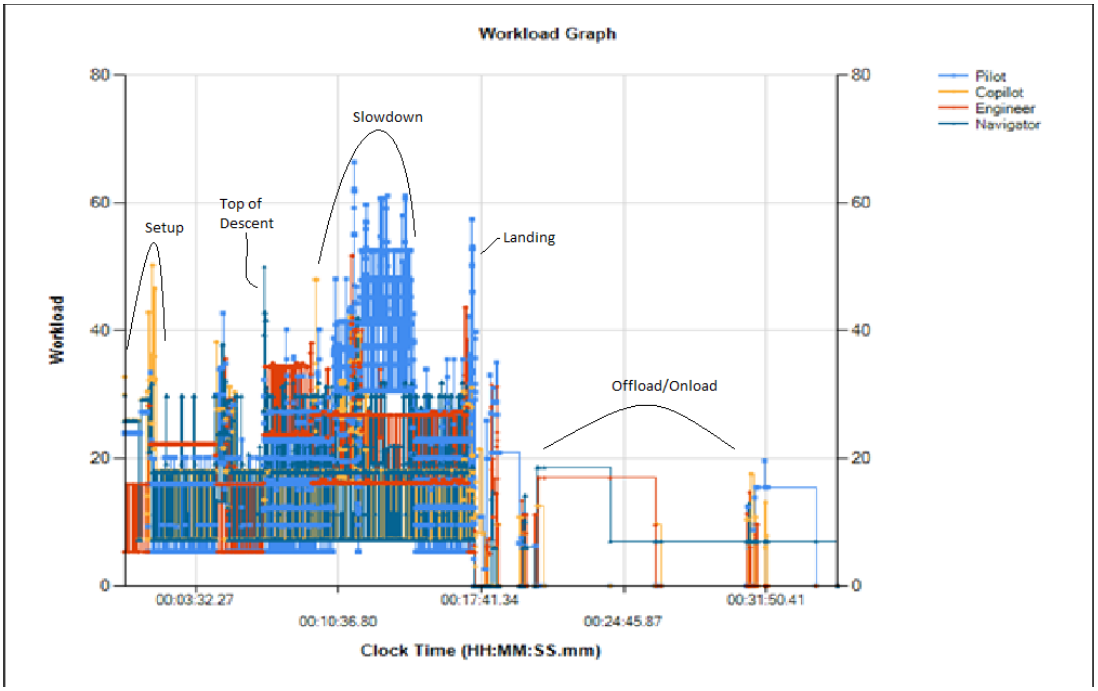

Figure 17: C-130H Maximum Effort Airland Workload Distribution

Again a workload of 40 units was used as a cutoff to qualitatively evaluate workload peaks (Table 16). This scenario generated far fewer workload peaks than the SKE Formation Airdrop Scenario. The C-130H Pilot encountered two sustained peaks: the first one occurring during level off and slowdown from high speed to final approach speed (3 minutes 53 seconds in duration, 66.4 maximum) and again while in the landing flare (10 seconds, 57.4 maximum). The C-130H Copilot encountered three workload peaks, of which the only sustained workload peak (20 seconds, 50,2 maximum) occurred early in the scenario while the Copilot was coordinating with air traffic control (ATC) on the radio, copying weather information, and scanning for threats. The other brief spikes were associated with configuring the landing gear and searching/identifying the landing runway. The Navigator only encountered one sustained peak (4 seconds, 50.0

maximum). Finally, the Engineer had two momentary spikes (<2 seconds) both associated with running checklists while monitoring aircraft performance.

Table 16: Maximum Effort Airland Workload Peaks (C-130H)

	Start Time (hh:mm:ss)	Duration (hh:mm:ss.ss)	Max Worload	Phase of Mission
Pilot	00:10:28.37	00:03:52.89	66.40	Slowdown
	00:17:06.74	00:00:09.69	57.40	Landing
Copilot	00:01:09.85	00:00:20.15	50.20	Enroute
	00:09:28.84	00:00:01.16	48.00	Descent
	00:11:12.35	0	42.10	Slowdown
Nav.	00:06:55.80	00:00:04.20	50.00	Descent
	00:11:33.22	0	42.00	Slowdown
Eng.	00:11:15.79	00:00:01.79	51.70	Slowdown
	00:16:54.22	00:00:00.78	43.60	Before Landing

Inspecting the workload profiles for the C-130J (Figure 18), the same oscillating bell curve appears, albeit at higher workload levels. Noticeably, the C-130J Copilot overloads very early in the scenario, while the Pilot overloads twice during slowdown and configuration.

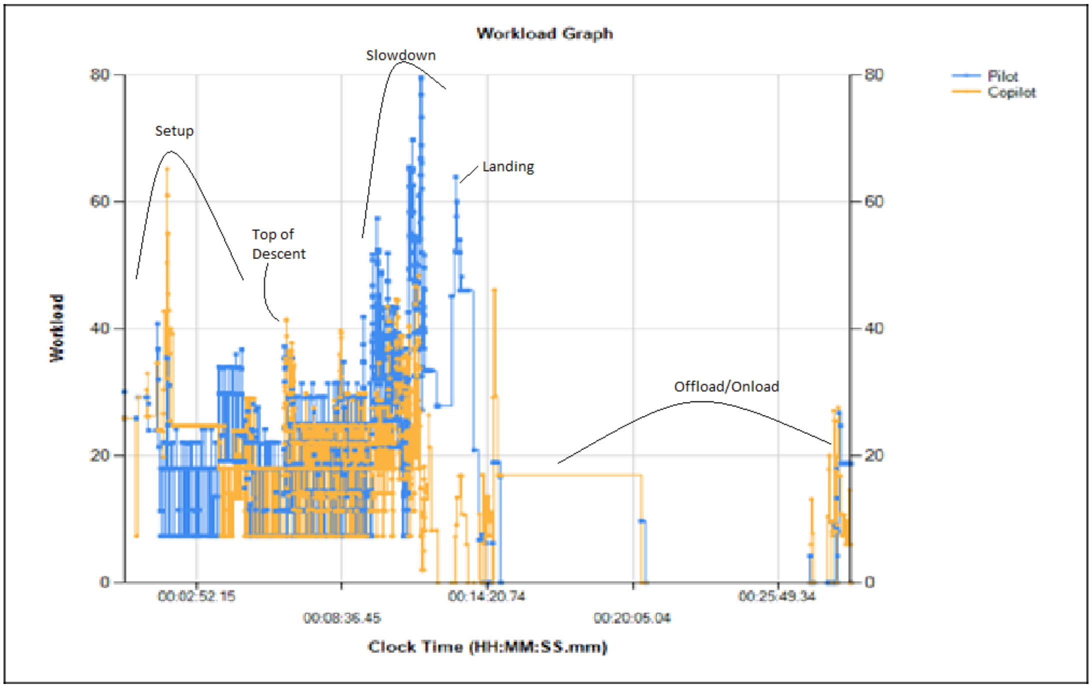

Figure 18: C-130J Maximum Effort Airland Workload Distribution

Table 17 shows that the C-130J Pilot encounters three workload peaks. Of the two sustained peaks, the first one (2 minutes 25 seconds, 79.5 maximum) occurs during the level off and slowdown. Compared to the C-130H Pilot during slowdown and configuration, the C-130J Pilot experienced a higher peak (79.5 versus 66.4) but high workload occurred in a shorter duration (2:25 versus 3:53). The second workload peak (50 seconds, 63.9 maximum) occurred just prior to and during landing, which was of longer duration and higher peak workload than the C-130H Pilot (10 seconds, 57.4 maximum).

Table 17: Maximum Effort Airland Workload Peaks (C-130J)

	Start Time (hh:mm:ss)	Duration (hh:mm:ss.	Max Worload	Phase of Mission
Pilot	00:01:18.91	0	40.80	Enroute
	00:09:26.25	00:02:24.50	79.50	Slowdown
	00:12:54.82	00:00:50.18	63.90	Landing
Copilot	00:01:33.86	00:00:11.14	65.20	Enroute
	00:06:23.62	0	41.40	Descent
	00:10:23.25	00:01:13.58	48.40	Slowdown

The C-130J Copilot also observed three workload peaks, of which two were sustained. At the beginning of the scenario, the Copilot becomes overloaded while communicating with ATC, copying weather, monitoring aircraft performance and scanning for threats. This first peak was shorter (11 versus 20 seconds) than the C-130H Copilot's peak, but resulted in a higher maximum workload value (65.2 versus 50.2) for the C-130J Copilot.

Summarizing the peak workload measurements in Table 18: the C-130J Pilot experiences only one more workload peak than the C-130H Pilot, while the Copilot experienced the same number of peaks. But, while the C-130J Pilot spends less time under high-workload conditions, the magnitude of those peaks were consistently greater than the C-130H Pilot's peaks. Thus, neither pilot held a conclusive advantage over the other. On the other hand, the C-130H Copilot had significantly shorter workload peaks with lower magnitudes, whereas the C-130J Copilot experienced overload. When the Navigator and Engineer are averaged into the Team SA, the C-130H aircrew experienced slightly fewer peaks, but spent noticeably less time operating in high workload and with a lower overall magnitude.

Table 18: Workload Peak Summary, Maximum Effort Airland

	# of Peaks	Total Duration	Avg Duration	Avg Workload	Max Workload
H Pilot	2	04:02.6	02:01.3	46.62	66.40
H Copilot	3	00:21.3	00:07.1	45.86	50.20
H Aircrew Avg	2.25	01:07.7	00:30.1	46.51	50.16
J Pilot	3	03:14.7	01:04.9	51.40	79.50
J Copilot	3	01:24.7	00:28.2	47.29	65.20
J Aircrew Avg	3	02:19.7	00:45.6	50.86	56.53

Just as in SKE Formation Airdrop scenario, 14 iterations of both the C-130H and C-130J Maximum Effort Airland models were run. Both average workload and maximum workload datasets were compiled as shown in Table 19 and Table 20.

Table 19: Maximum Effort Airland Average Workload Values

	C-130H Average Workloads					C-130J Average Workloads		
Iteration	H Navigator	H Engineer	H Pilot	H Copilot	H Aircrew	J Pilot	J Copilot	J Aircrew
1	15.87	21.03	21.55	12.93	17.84	22.09	18.85	20.47
2	15.87	20.28	21.75	12.60	17.62	21.81	18.78	20.29
3	15.18	19.85	21.73	12.17	17.23	21.77	17.68	19.72
4	14.73	18.84	20.86	11.62	16.51	22.26	18.23	20.25
5	15.19	20.37	22.05	11.71	17.33	22.41	19.79	21.10
6	14.23	19.45	21.55	11.85	16.77	22.47	18.58	20.52
7	14.66	20.14	21.59	12.19	17.15	21.81	18.50	20.16
8	15.37	20.95	22.30	12.45	17.77	21.85	19.01	20.43
9	15.00	18.97	21.75	11.72	16.86	21.04	16.95	18.99
10	14.26	18.95	21.34	11.00	16.39	21.80	18.34	20.07
11	14.33	19.31	21.35	11.25	16.56	21.76	18.04	19.90
12	14.71	18.38	21.23	11.48	16.45	21.05	17.14	19.09
13	14.90	19.72	21.75	12.05	17.07	21.91	18.41	20.09
14	14.59	20.27	21.95	12.57	17.34	21.69	18.90	20.29
Averages	**14.92**	**19.75**	**21.62**	**11.97**	**17.06**	**21.84**	**18.37**	**20.10**

Table 20: Maximum Workload Values, Maximum Effort Airland Scenario

	C-130H Maximum Workloads					C-130J Maximum Workloads		
Iteration	H Navigator	H Engineer	H Pilot	H Copilot	H Aircrew	J Pilot	J Copilot	J Aircrew
1	57.70	51.70	65.30	56.90	57.90	80.30	61.00	70.65
2	47.10	51.70	65.30	50.20	53.58	75.80	50.60	63.20
3	48.70	51.70	65.30	50.20	53.98	86.30	49.60	67.95
4	47.80	41.10	65.30	50.20	51.10	71.60	56.90	64.25
5	45.70	51.70	65.30	50.20	53.23	89.20	55.00	72.10
6	51.50	51.70	65.30	60.70	57.30	82.40	53.50	67.95
7	47.80	51.70	65.30	56.90	55.43	77.90	61.00	69.45
8	47.80	47.60	66.40	50.20	53.00	71.20	66.90	69.05
9	46.10	51.70	60.70	56.90	53.85	79.50	50.60	65.05
10	46.70	51.70	66.20	50.20	53.70	76.40	61.00	68.70
11	46.10	52.20	64.30	50.50	53.28	75.30	52.00	63.65
12	57.70	43.60	65.30	56.90	55.88	75.80	50.40	63.10
13	49.10	51.70	65.30	50.20	54.08	77.90	56.90	67.40
14	57.70	51.70	64.30	61.10	58.70	71.20	55.00	63.10
Averages	**49.82**	**50.11**	**64.97**	**53.66**	**54.64**	**77.91**	**55.74**	**66.83**

Conducting t-test evaluation of these data, the results are mixed. Data that satisfies the *t*-test also meets the stricter significance criteria of the Bonferroni post hoc test to account for the family-wise error rate ($m = 3$, $\alpha_{\text{Bonferroni}} = 0.017$). The Pilot has an insignificant difference in average workloads while the Copilot has an insignificant difference in maximum observed workload. When factoring in the Navigator and Engineer, the C-130H team experiences lower average and maximum workload peaks than the C-130J team. Thus automation appears to increase or have no effect on workload in this scenario depending on the operator.

Table 21: T-test results for Maximum Effort Airland data

	Average Workload			Maximum Workload		
α=0.05	Pilot	Copilot	Aircrew	Pilot	Copilot	Aircrew
***p*- value**	0.170	<0.001	<0.001	<0.001	0.293	<0.001
Lower Workload	Neither	H	H	H	Neither	H

Situation Awareness Analysis

SKE Formation Airdrop Scenario

The situation awareness assessment began by running a single iteration of the scenario and exporting the resulting charts for qualitative analysis. Strategic SA (Figures 19 and 20), which is not connected to any particular task or element, ran as a dedicated function in the task network (III. Methodology, Figure 13), computed a strategic SA value dependent on total experienced workload. The workload thresholds for High (0.75), Medium (0.75), and Low SA (0.25) were set to correspond with Endsley's theoretical SA-Workload Function (II. Literature Review, Figure 5). Thus, each operator would maintain high strategic SA until approaching overload, then strategic SA would diminish until it reached zero immediately prior to overload. Of note is that high strategic SA is maintained by all operators for the vast majority of the simulation run. These momentary dips correspond well to the workload peaks shown in Figures 15 and 17.

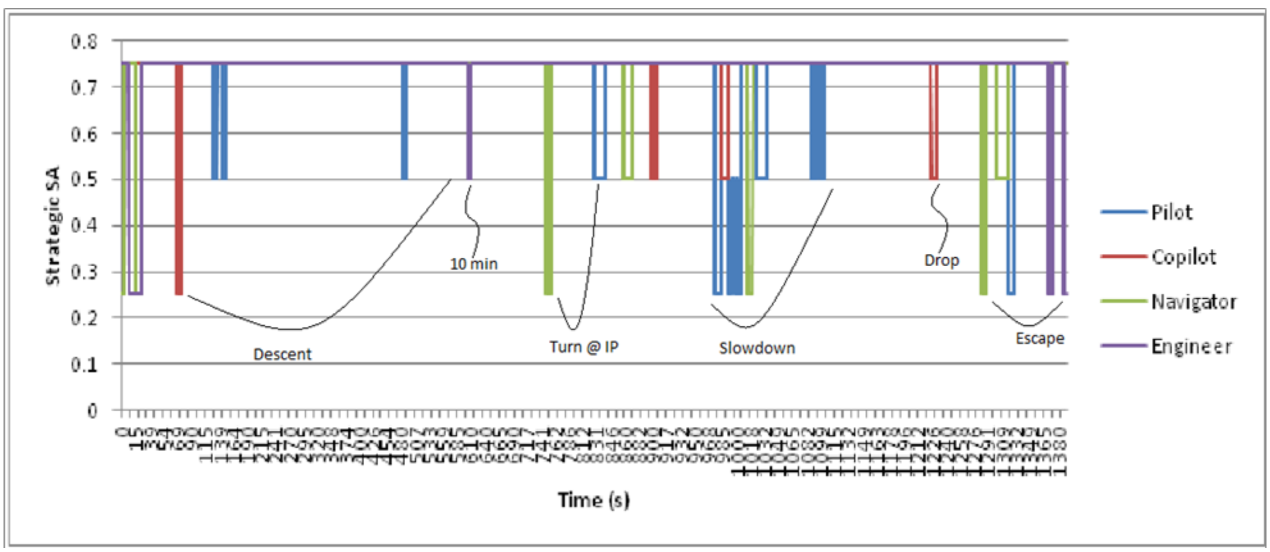

Figure 19: C-130H SKE Formation Airdrop Strategic SA Distribution

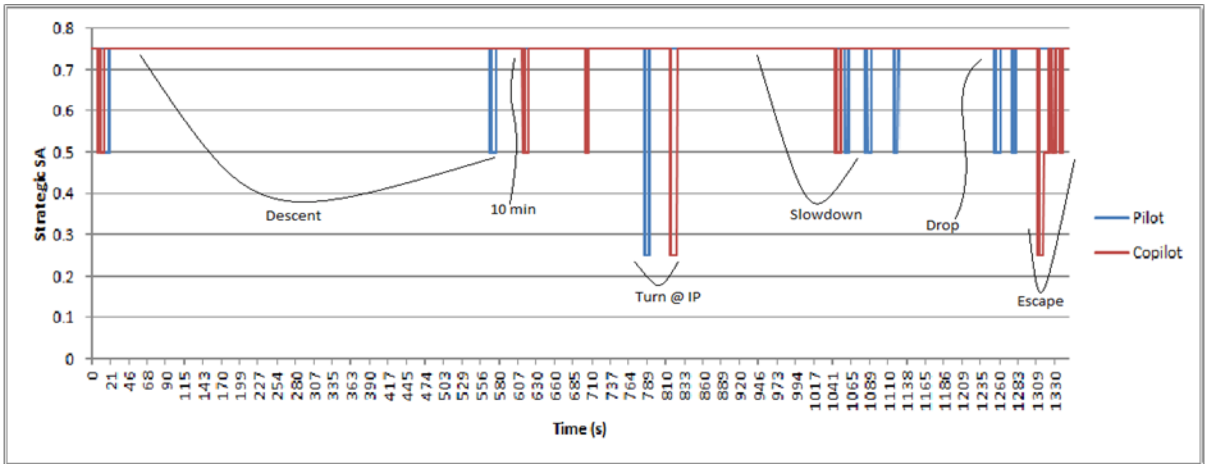

Figure 20: C-130J SKE Formation Airdrop Strategic SA Distribution

Tactical SA, which is SA linked to specific tasks, was coded into each IMPRINT task in both scenarios and both aircraft. When a given task was run, the beginning effect incrementally increased tactical SA to the applicable operators, and the ending effect incrementally decreased tactical SA by that same amount. Any elements of tactical SA important enough to store become represented by the strategic SA function. Not all tasks had an effect on tactical SA. Of those tasks that did positively increment tactical SA, their values were normalized to a range of 0-0.25 in order to fit with strategic SA scoring (Chapter III. Methodology: Measuring Workload and Situation Awareness). Note that more than one Tactical SA task can be accomplished simultaneously, thus permitting instantaneous Tactical SA to exceed 0.25. Tactical SA (Figures 21 and 22) was charted in a similar fashion to strategic SA.

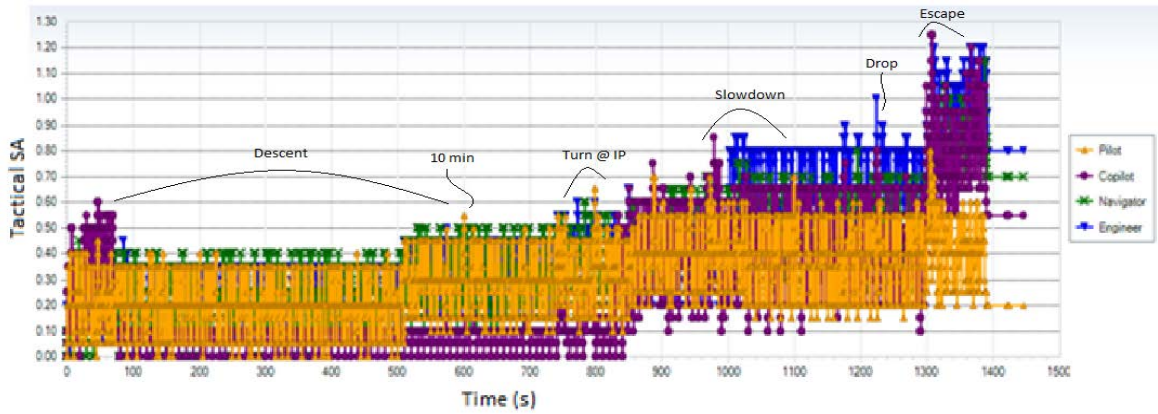

Figure 21: C-130H SKE Formation Airdrop Tactical SA Distribution

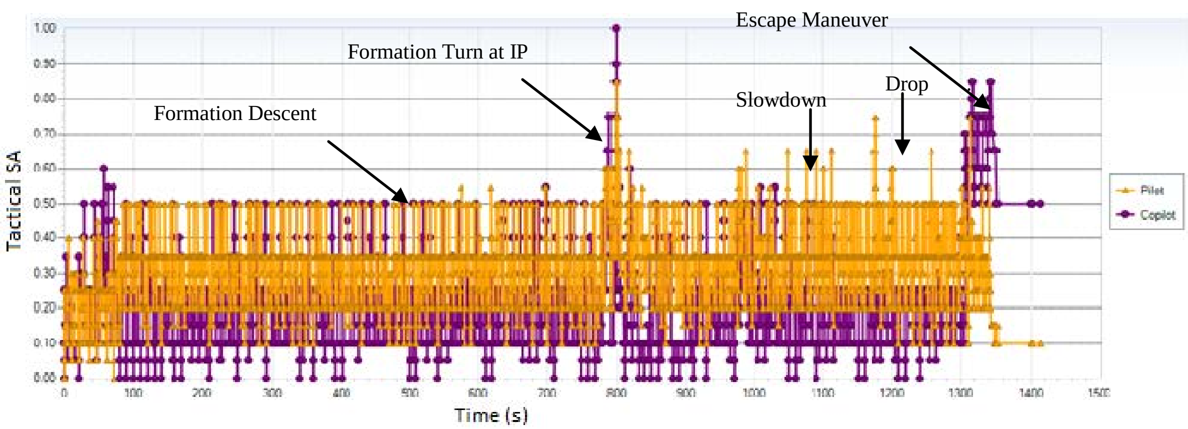

Figure 22: C-130J SKE Formation Airdrop Tactical SA Distribution

Inspecting Figure 21 reveals a sine wave centered on 0.20 units with amplitudes between 0.15-0.20. The sine wave increases as the scenario progresses possibly suggesting that as the aircraft nears the objective area and/or descends, there is an increase in SA-additive tasks. However, this effect is not observed in the C-130J (Figure 22). Of note, there are frequent FCI commands and verbal communications (both 0.05 tactical SA for the listener) and numerous gauge or instrument readings (0.15 tactical SA) in the C-130H iteration. Comparatively, the C-130J passes FCI commands transparently,

but both pilots refer to a HUD (0.15 in cruise and 0.20 in low level) and color multifunction display or moving map (0.25 tactical SA) which appears to have a significant effect on tactical SA. The C-130J maintains a more consistent linear sine wave centered on 0.35 with an amplitude of 0.15. The two formation turns: one at the Initial Point (IP) and the other while flying the escape maneuver, markedly improve tactical SA to the C-130J crew, since the pilots reference a multifunction display. Thus, it appears upon inspection that the crew of the C-130J has more tactical SA.

Simply adding tactical SA to strategic SA produces total SA. The C-130H shows that total SA remains relatively constant throughout the SKE formation airdrop with an increase in Copilot and Engineer total SA during the escape maneuver at the end of the simulation because their tactical SA increases significantly (Figure 23). Strategic SA negatively impacts total SA during the previously identified workload peaks: particularly during the formation turn, slowdown and escape maneuver (Pilot only). Conversely, C-130J total SA peaks during the formation turn and escape maneuver, but similarly declines during the slowdown (Figure 23). All total SA distributions are centered near 1.0, and no discernible advantage to either aircraft can be gathered by qualitatively comparing Figure 23and Figure 24.

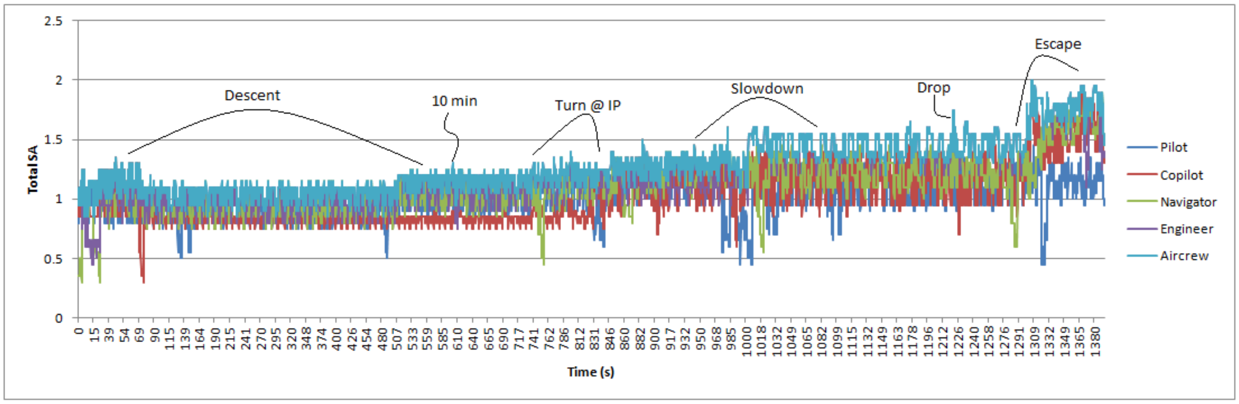

Figure 23: C-130H SKE Formation Airdrop Total SA Distribution

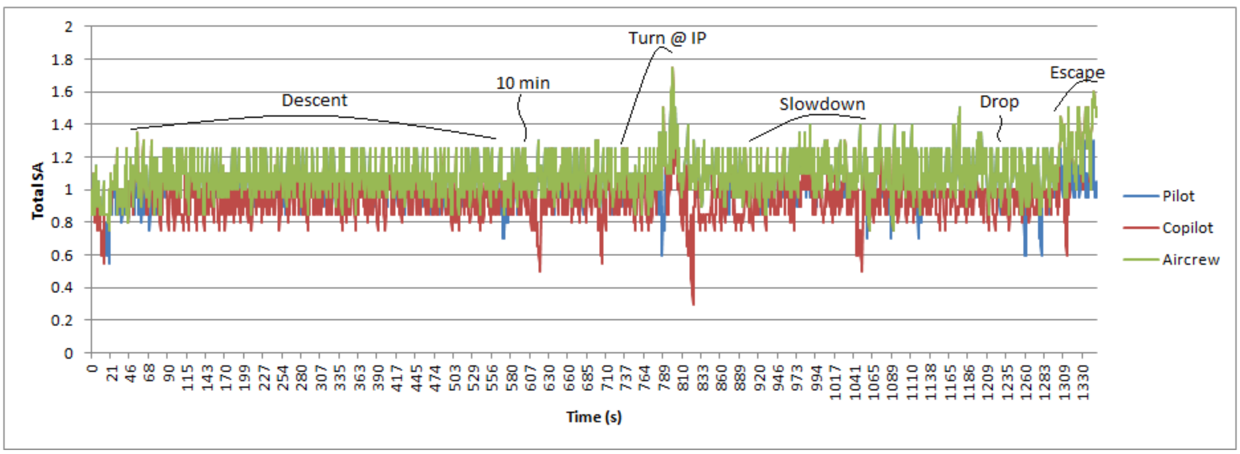

Figure 24: C-130J SKE Formation Airdrop Total SA Distribution

Because the SA outputs impose significantly higher computational effort, only five simulation runs were conducted to examine SA (Table 22, Table 23). Despite the limited number of iterations, standard deviation between data was low. Similar to the workload analysis, data that satisfies the *t*-test also meets the stricter significance criteria of the Bonferroni post hoc test to account for the family-wise error rate (m = 3, $\alpha_{\text{Bonferroni}}$ = 0.017). Examining the quantitative data from these five iterations, the C-130H exhibited higher strategic SA for both the Pilot and Copilot (Table 24). However results

were mixed for tactical SA: the C-130J Pilot had more tactical SA while the C-130H Copilot had more tactical SA. Thus, total SA was inconclusive for the Pilot, but the C-130H Copilot and aircrew (Navigator and Engineer included) had more total SA.

Table 22: SKE Formation Airdrop Average SA Data (C-130H)

	Strategic SA				Tactical SA				Total SA				
Iteration	**Pilot**	**Copilot**	**Navigator**	**Engineer**	**Pilot**	**Copilot**	**Navigator**	**Engineer**	**Pilot**	**Copilot**	**Navigator**	**Engineer**	**Team**
1	0.674	0.694	0.685	0.697	0.280	0.274	0.371	0.468	0.954	0.969	1.056	1.166	1.220
2	0.677	0.698	0.683	0.700	0.299	0.271	0.361	0.470	0.976	0.969	1.043	1.170	1.219
3	0.676	0.697	0.687	0.698	0.285	0.274	0.381	0.494	0.962	0.971	1.068	1.192	1.241
4	0.675	0.699	0.683	0.698	0.295	0.261	0.375	0.490	0.969	0.959	1.058	1.188	1.238
5	0.671	0.697	0.684	0.696	0.277	0.258	0.385	0.476	0.948	0.955	1.069	1.171	1.226
Average	**0.675**	**0.697**	**0.684**	**0.698**	**0.287**	**0.268**	**0.374**	**0.480**	**0.962**	**0.965**	**1.059**	**1.177**	**1.229**

Table 23: SKE Formation Airdrop Average SA Data (C-130J)

	Strategic SA		Tactical SA		Total SA		
Iteration	**Pilot**	**Copilot**	**Pilot**	**Copilot**	**Pilot**	**Copilot**	**Team**
1	0.659	0.658	0.308	0.221	0.967	0.879	1.009
2	0.664	0.661	0.303	0.226	0.967	0.887	1.019
3	0.654	0.651	0.302	0.210	0.956	0.861	0.995
4	0.660	0.660	0.300	0.220	0.960	0.880	1.006
5	0.649	0.652	0.306	0.211	0.955	0.863	1.001
Average	**0.657**	**0.657**	**0.304**	**0.218**	**0.961**	**0.874**	**1.006**

Table 24: T-test results for SKE Formation Airdrop SA Data

Strategic SA		Tactical SA		Total SA		
Pilot	**Copilot**	**Pilot**	**Copilot**	**Pilot**	**Copilot**	**Team**
0.001	<0.001	0.036	<0.001	0.869	<0.001	<0.001
H	H	J	H	Neither	H	H

Maximum Effort Airland Scenario

The Maximum Effort Airland scenario incorporated the same situation awareness (SA) algorithms found in SKE Formation Airdrop scenario. A single iteration run of this scenario on both C-130H and C-130J model is shown in Figure 25 and Figure 26. Not surprisingly, most operators spend of their time with high strategic SA (0.75) with the entirety of both simulations showing high SA for all operators after landing and while the

aircraft is on the ground. Inspecting both figures shows sustained excursions to lower levels of SA commensurate with increased setting up for the descent and the demanding slowdown/configuration phase following the 600-second mark. No clear qualitative strategic SA comparison between the C-130H and C-130J can be made for the Pilot or Copilot, but it appears that the C-130H has slightly higher team strategic SA.

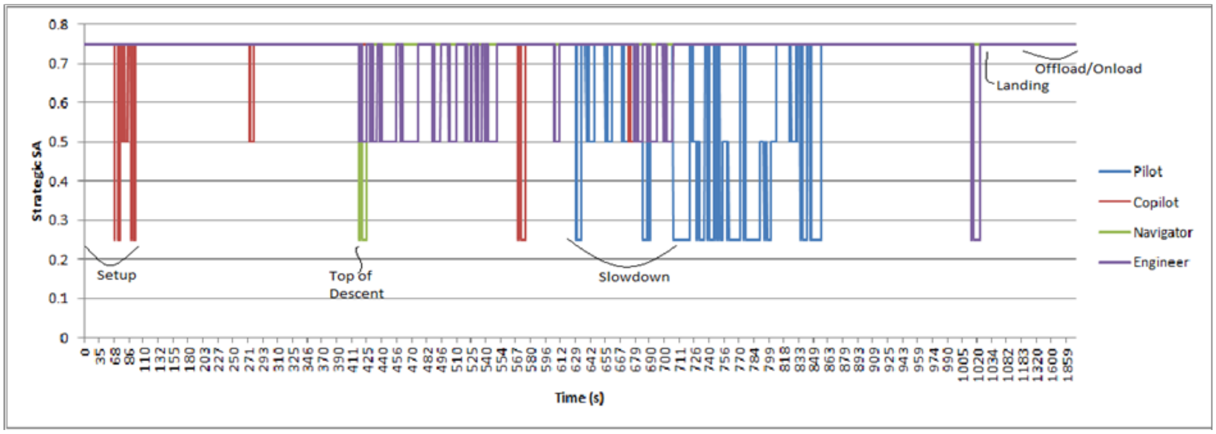

Figure 25: C-130H Maximum Effort Airland Strategic SA Distribution

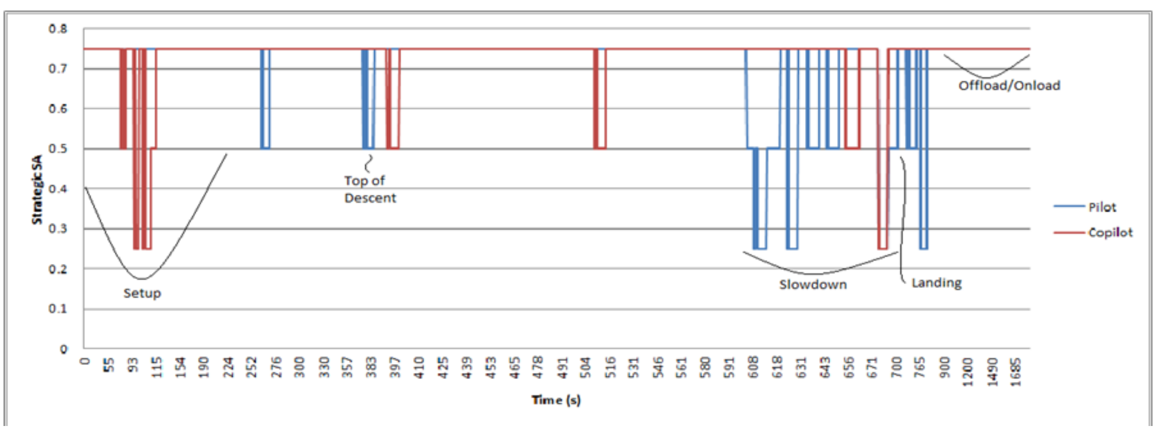

Figure 26: C-130J Maximum Effort Airland Strategic SA Distribution

Tactical SA trends follow similar patterns for the C-130H (Figure 27) and C-130J (Figure 28): a steadily increasing sine wave with a momentary spike in Pilot tactical SA

immediately prior to touchdown and low tactical SA for all operators while the aircraft is on the ground. The first 400 seconds of the simulation show no conclusive advantage in tactical SA, however, the C-130J appears to have slightly more tactical SA than the C-130H (C-130J: sine centered on 0.30, amplitude 0.2; C-130H: sine centered on 0.20, amplitude 0.15-0.2) from 400 seconds until touchdown. Once on the ground the C-130J had almost no tactical SA, while the C-130H Navigator maintained a constant 0.10 while standing in the safety observer position and watching the offload occur in the back of the aircraft.

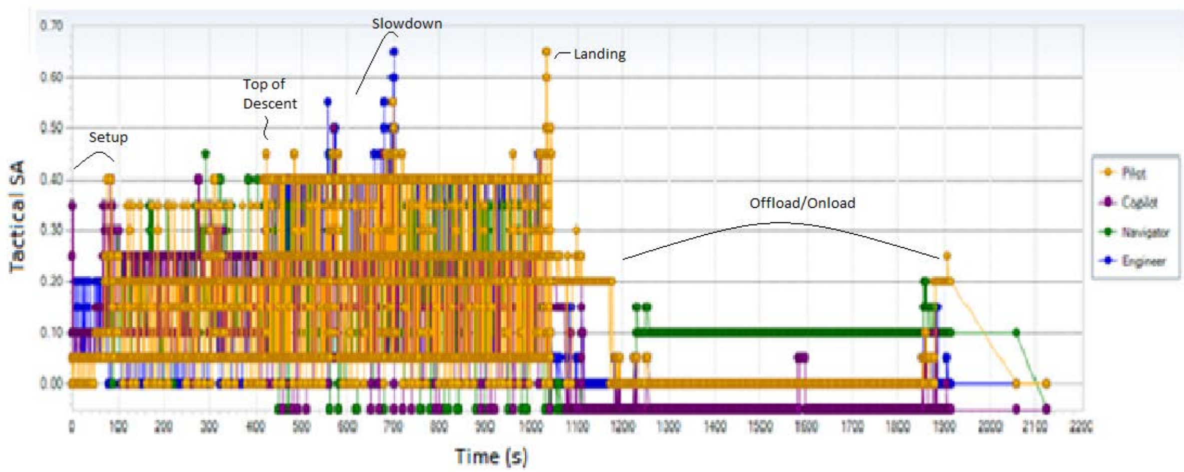

Figure 27: C-130H Maximum Effort Airland Tactical SA Distribution

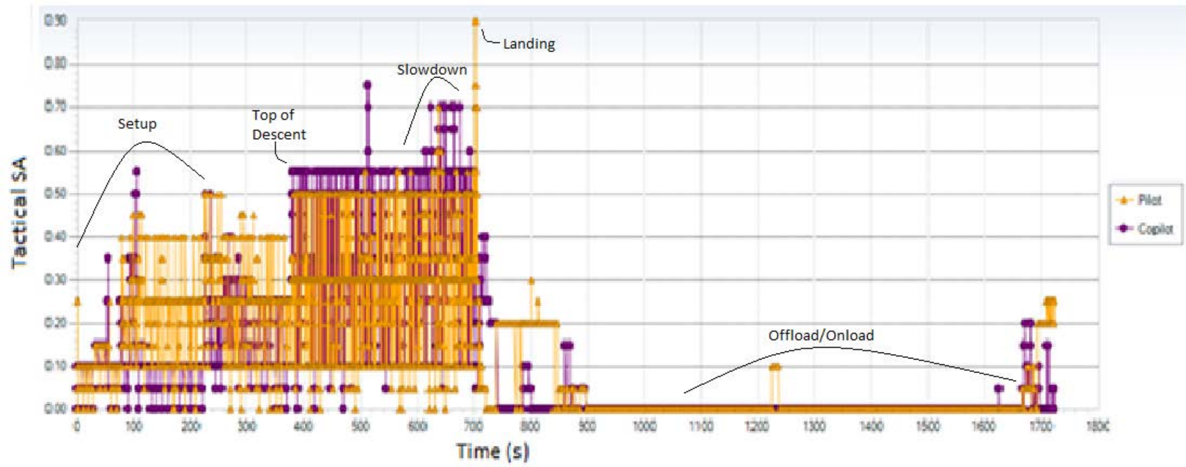

Figure 28: C-130J Maximum Effort Airland Tactical SA Distribution

When computing total SA, it is interesting to note that the average total SA distribution remains relatively constant while the aircraft is on the ground and few tactical SA tasks are being accomplished (Figure 29, Figure 30). In both C-130H and C-130J, the Pilot's total SA declined after landing, as expected, when tasks diminished, but the Copilot's and Engineer's total SA remained high while the aircraft was on the ground. Strategic SA appears to have had the largest negative impact on total SA, which corresponds to high-workload periods associated with preparing for the tactical approach, slowdown/configuration, and final approach. However, once the autopilot is disengaged and the tactical approach begins, the amplitude of the sine wave increases due to tactical SA associated with basic aircraft control tasks.

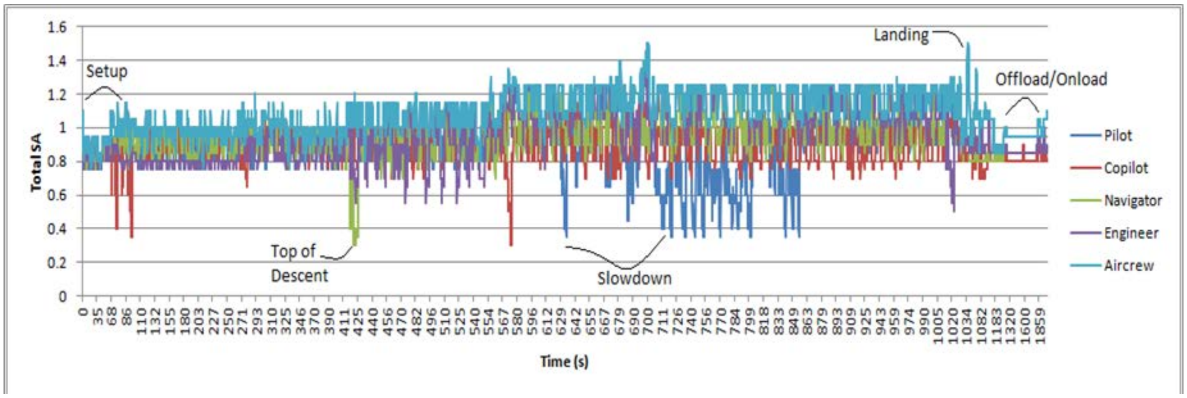

Figure 29: C-130H Maximum Effort Airland Total SA Distribution

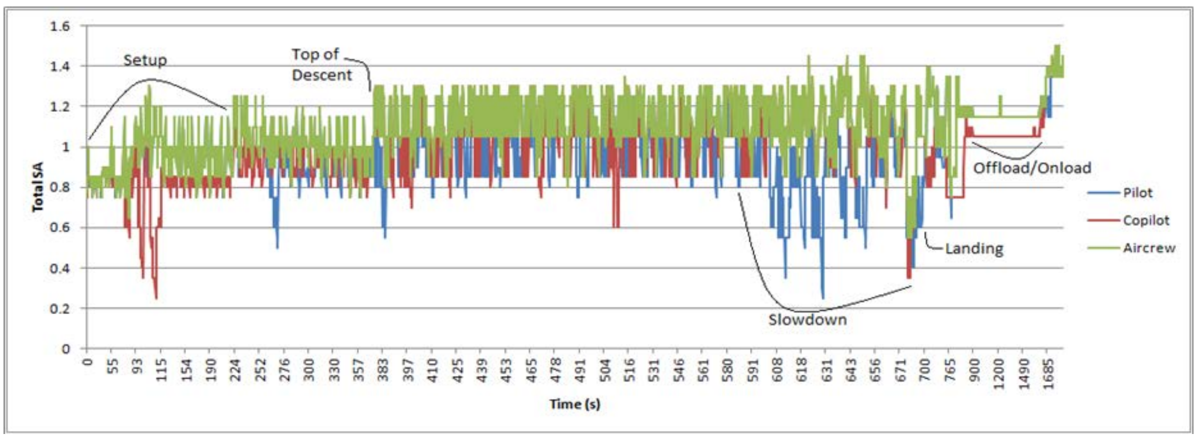

Figure 30: C-130J Maximum Effort Airland Total SA Distribution

Similar to the SKE Formation Airdrop scenario, five iterations were run to build a dataset on SA for both aircraft (Table 25, Table 26). Despite the limited number of iterations, standard deviation between data was low. Similar to the workload analysis, data that satisfies the *t*-test also meets the stricter significance criteria of the Bonferroni post hoc test to account for the family-wise error rate ($m = 3$, $\alpha_{\text{Bonferroni}} = 0.017$). Examining the data (Table 27), the C-130J Pilot experienced similar strategic SA, but higher tactical and higher total SA than the C-130J Pilot. The Copilot experienced lower

strategic SA in the C-130J, but the higher tactical SA which offset and led to higher total SA than the C-130H Copilot. Thus, while the C-130J Pilot and Copilot had higher total SA than their C-130H counterparts, the aircrew as a team experienced no significant difference in total SA because the C-130H Navigator and Engineer made sufficient contributions to even the differences.

Table 25: Maximum Effort Airland Total SA Data (C-130H)

	Strategic SA				Tactical SA				Total SA				
Iteration	**Pilot**	**Copilot**	**Navigator**	**Engineer**	**Pilot**	**Copilot**	**Navigator**	**Engineer**	**Pilot**	**Copilot**	**Navigator**	**Engineer**	**Team**
1	0.627	0.680	0.684	0.657	0.223	0.157	0.220	0.270	0.849	0.837	0.904	0.927	1.041
2	0.615	0.680	0.682	0.655	0.211	0.151	0.219	0.261	0.826	0.831	0.901	0.916	1.028
3	0.621	0.681	0.681	0.662	0.164	0.186	0.213	0.255	0.786	0.867	0.895	0.917	1.018
4	0.620	0.680	0.682	0.659	0.166	0.186	0.219	0.212	0.786	0.866	0.901	0.871	1.015
5	0.621	0.677	0.675	0.656	0.172	0.149	0.259	0.206	0.793	0.827	0.934	0.862	1.023
Average	**0.621**	**0.680**	**0.681**	**0.658**	**0.187**	**0.166**	**0.226**	**0.241**	**0.808**	**0.846**	**0.907**	**0.898**	**1.025**

Table 26: Maximum Effort Airland Total SA Data (C-130J)

	Strategic SA		Tactical SA		Total SA		
Iteration	**Pilot**	**Copilot**	**Pilot**	**Copilot**	**Pilot**	**Copilot**	**Team**
1	0.625	0.678	0.290	0.285	0.914	0.963	1.048
2	0.639	0.668	0.263	0.239	0.902	0.907	1.004
3	0.625	0.676	0.262	0.247	0.887	0.923	1.013
4	0.644	0.671	0.256	0.247	0.899	0.918	1.017
5	0.635	0.667	0.257	0.253	0.892	0.920	1.012
Average	**0.633**	**0.672**	**0.266**	**0.254**	**0.899**	**0.926**	**1.019**

Table 27: T-Test results for Maximum Effort Airland SA data

	Strategic SA		Tactical SA		Total SA		
α=0.05	**Pilot**	**Copilot**	**Pilot**	**Copilot**	**Pilot**	**Copilot**	**Team**
***p*-value**	0.075	0.015	<0.001	<0.001	<0.001	0.004	0.316
Higher SA	Neither	H	J	J	J	J	Neither

Situation Awareness-Workload Relationship

While not a direct requirement to answer the investigative questions, a relationship between SA and workload can easily be measured. The strategic SA functions were programmed to be dependent variables of their operator's workload. Therefore, there was an intentionally direct (negative) correlation between strategic SA

and total workload. However, tactical SA remained independent of workload to an extent, although performing additional key tactical tasks will increase both tactical SA and workload. It was possible for the operators to maintain high SA under high workload, provided the operator's tasks also contributed towards SA. As a result, a scatter plot (Figure 31 and Figure 33) of total SA and workload revealed no discernible trend. This dissociation corresponds well with Endsley's (1993) experimental findings.

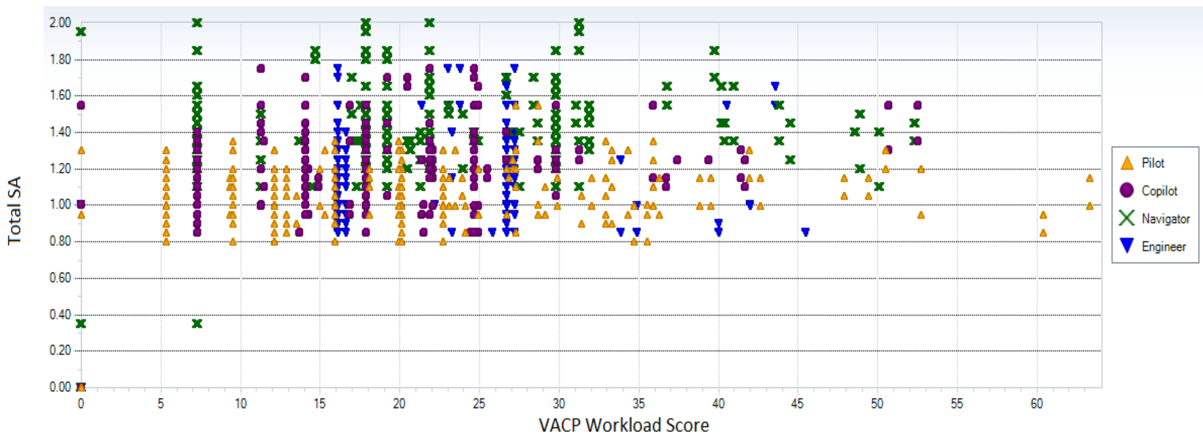

Figure 31: C-130H SA-Workload Distribution, SKE Formation Airdrop

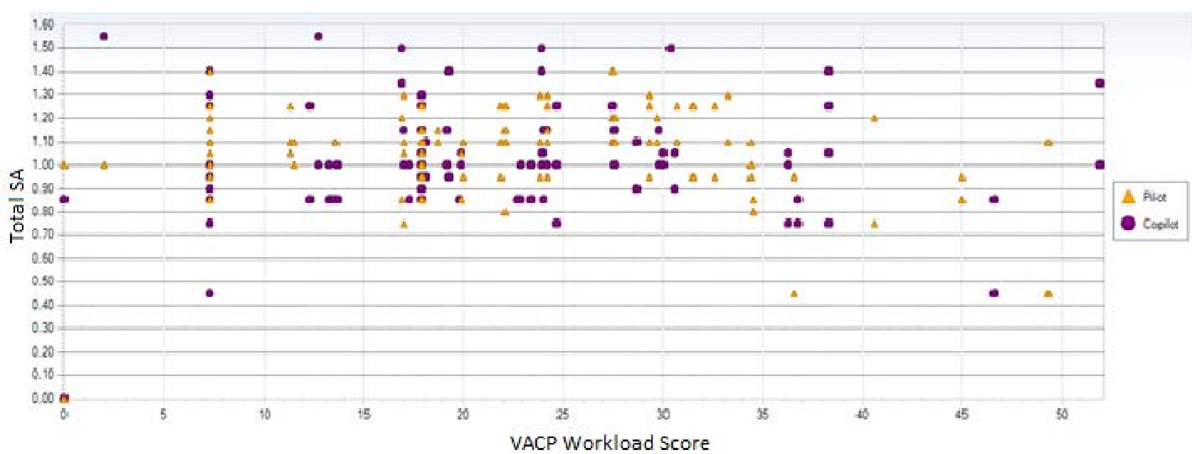

Figure 32: C-130J SA-Workload Distribution, SKE Formation Airdrop

The Maximum Effort Airland data exhibits high variance, however a loose trend begins to emerge that shows somewhat less dissociation than the SA-Workload relationship generated during the SKE Formation Airdrop scenario. The C-130H Pilot, Copilot, and Navigator (Figure 33) have total SA centered between approximately 0.90 and 1.00 until workload exceeds 32 units. At higher workloads, SA decreases and increases in variance. The C-130J Pilot and Copilot (Figure 34) have total SA centered at approximately 1.10 until workload exceeds 30 units, after which SA decreases and variance increases in an identical pattern to the C-130H's distribution. As an outlier, the Engineer has low total SA at lower workload and increases total SA as workload increases. Interestingly, these loosely correlate to Endsley's SA-Workload theory shown in Figure 5 (found in Chapter II. Literature Review).

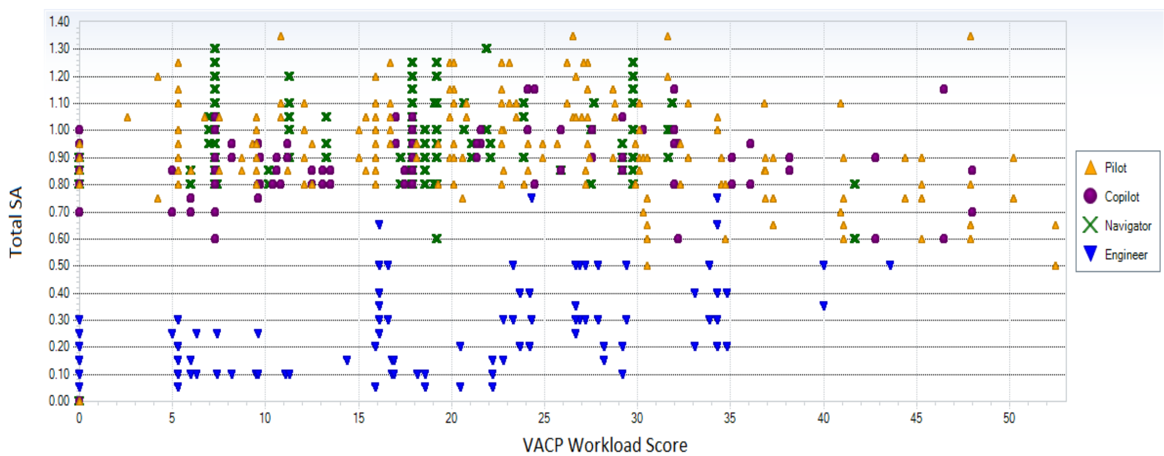

Figure 33: C-130H Maximum Effort Airland SA-Workload Distribution

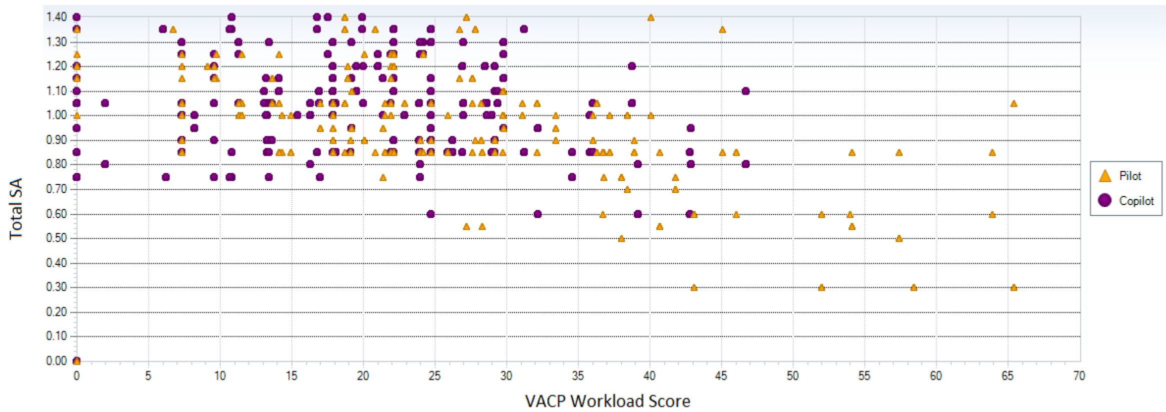

Figure 34: C-130J Maximum Effort Airland SA-Workload Distribution

Summary

After examining the data, results were mixed and depended on both the situation and the aircraft. No particular operator or aircraft emerged as distinctly advantageous across both scenarios. The C-130J Pilot experienced less severe workload peaks (lower frequency, duration and intensity), lower average and maximum workload than the C-130H Pilot for airdrop, however this did not result in any difference in total SA. The Pilot's peak workload analysis and average workload were inconclusive for the airland scenario, but the C-130J Pilot experienced a lower maximum workload, yet maintained higher total SA than the C-130H Pilot.

The C-130J Copilot did not benefit from the increased automation as much as the airdrop scenario: workload peaks increased very slightly in frequency, duration, and intensity, while average workload decreased. Furthermore, the C-130H Copilot had higher total SA. During the airland scenario, the C-130J Copilot experienced the same frequency of workload peaks, but those peaks were of longer duration and higher

intensity, which also contributed to a higher average workload than the C-130H Copilot. Despite this, the C-130J Copilot had higher total SA than the C-130H Copilot.

As a crew, the C-130J experienced the same number of workload peaks, but of shorter duration and slightly lower intensity which contributed towards lower average and maximum workload values than the C-130H aircrew during the airdrop scenario. During the airland scenario, the C-130J averaged the same number of workload peaks, but thanks to the Copilot interface and task distribution, their duration and intensity were higher. Similarly, the C-130J aircrew experienced higher average workload throughout the scenario. However, the C-130J team SA was never higher than the C-130H. During the formation airdrop, neither the C-130J Pilot or Copilot experienced higher SA than their C-130H counterparts, so when Navigator and Engineer contributions towards team SA are considered, the C-130H actually had more total SA. However, while the C-130J Pilot and Copilot had higher total SA than the C-130H Pilot and Copilot, this was sufficiently offset by the contributions by the Navigator and Engineer to the point where both aircraft had identical team SA on average.

V. Conclusions and Recommendations

Chapter Overview

This chapter answers the hypotheses created by the investigative questions and draws research conclusions of this thesis based on the analysis performed in Chapter IV. The significance of these conclusions is discussed along with recommendations for actions and recommendations for future research.

Investigative Questions Answered

Investigative Question #1

How does the use of automation affect workload during station keeping equipment (SKE) formation airdrop? To answer this question the following hypothesis was developed: automated cockpits (C-130J) result in lower workload than non-automated cockpits (C-130H) during SKE formation airdrop. In this scenario automation significantly reduced average workload, maximum workload, the occurrence of workload peaks, their duration and magnitude for the Pilot. Automation in the C-130J reduced the Copilot's average workload, had no significant change in maximum workload, and resulted in a slight increase in the occurrence and duration of workload peaks. When averaging the entire crew, automation significantly reduced average and maximum workloads, and reduced the occurrence and duration of workload peaks slightly. Therefore this research rejects the null hypothesis and finds support for increased automation reducing workload during the times the automation is performing to

expectation. During the SKE Formation Airdrop scenario the aircraft configuration, with the caveat that while Copilot average workload decreased with automation, had a negligible effect on peak workload.

Investigative Question #2

How does the use of automation affect situation awareness during SKE formation airdrop? To answer this question the following hypothesis was developed: automated cockpits (C-130J) result in higher SA than non-automated cockpits (C-130H) during SKE formation airdrop. Three measures of SA were created to measure this: strategic, tactical, and total with total SA becoming the test statistic.

Due to the high level of variation in the SA graphs, no difference between the automated and non-automated SA could be qualitatively determined. However a quantitative analysis over five iterations showed that the Pilot experienced no significant difference in SA in the automated cockpit of the C130J. The Copilot and aircrew team SA was higher in the C-130H cockpit during the SKE Formation Airdrop Scenario. Because the difference in average total SA was either insignificant (Pilot) or lower in the automated cockpit (Copilot team), this research fails to find sufficient evidence that automation improves situation awareness.

Investigative Question #3

How does automation affect aircrew workload during an airland mission?

To answer this question the following hypothesis was developed: automated cockpits (C-130J) result in lower workload than non-automated cockpits (C-130H) during airland missions. In the Maximum Effort Airland scenario, automation did not significantly affect Pilot workload by any of the measures used (automation only reduced

the duration of Pilot workload peaks). However Copilot average workload increased on the automated system as well as the occurrence, magnitude, and duration of Copilot and crew workload peaks. Maximum observed workload increased for Pilot, Copilot, and the crew average. Because automation had either neutral or negative effects on workload, this research fails to find sufficient evidence to support the alternative hypothesis that increased automation reduces workload for Maximum Effort Airland missions.

Investigative Question #4

How does automation affect aircrew situation awareness during an airland mission?

To answer this question the following hypothesis was developed: automated cockpits (C-130J) result in higher average SA than non-automated cockpits (C-130H) during SKE formation airdrop. Three measures of SA were created to measure this: strategic, tactical, and total with total SA becoming the test statistic. The automated cockpit had mixed results for total SA: both Pilot and Copilot had higher total SA as individuals, however the contributions made by the Navigator and Engineer offset those differences such that no statistically significant difference emerges. Thus, while the automation effectively replaces the Navigator and Engineer, there is insufficient evidence to support the alternative hypothesis that increased automation improves situation awareness for airland missions.

Conclusions of Research

Workload Conclusions

The effects of automation on aircrew workload depend significantly on the situation at hand. Automation is far more complex than a simple on/off switch. Even though automated cockpits can take over several tasks from the human operator, the human operator is not necessarily left idle. Task burdens can shift from manipulating and doing to programming and supervising. While critical points exist in generally similar locations and times for both scenarios, automation can reduce workload peaks associated these critical times, but it also has the potential to create new critical points with high workload.

In this experiment, the highly automated C-130J showed significant reduction in all aspects of Pilot workload during the SKE Formation Airdrop Scenario by automating a majority of formation position maintenance and relaying formation commands. This was especially true during formation turns and the critical slowdown-airdrop-escape phase surrounding the drop zone. The C-130J Copilot had lower average workload, but slight increases in the number, duration, and intensity of workload peaks when no workload strategy was employed. Overall, the C-130J reduced the average workload and duration of peak workload, while having little to no effect on the number or intensity of those workload peaks. Thus, for the formation airdrop, the C-130J effectively reduces workload when substituting automation for the Navigator and Engineer.

Because the C-130J Pilot typically manually flies the descent and landing during a tactical approach to a landing zone in a fashion similar to the C130H, there was a negligible difference in average workload and the number of workload peaks between

cockpit designs for the Maximum Effort Airland Scenario. However, the C-130J Pilot experienced shorter workload peaks but of much greater intensity when no workload strategy was employed. The C-130J Copilot experienced higher average workload, and longer, more intense workload peaks. Overall the C-130J slightly increased average workload, and increased the intensity of peak workload beyond the overload threshold. Thus, for the airland scenario, the C-130J does not reduce workload by substituting automation for the Navigator and Engineer and requires the use of workload strategies to mitigate peak workload.

Situation Awareness Conclusions

Situation awareness depends not only on the situation, how the human operator interacts with that situation and whether the tasks performed contribute to or degrade SA and by how much. Certain tasks can add to SA when they provide information to the operator or utilize working memory. The automation of the C-130J was shown to increase total Pilot SA during both the formation airdrop and the airland scenarios. Since the Pilot was able to focus more effort on tasks that provide information, the quantity of information increased. Design improvements to the C-130J, namely the multifunction display, automated systems alerts, heads-up display, and better computing power improved the quality of data. The C-130J Copilot also experienced increased SA during the airland scenario (for the same reasons) but did not see an improvement over the C-130H Copilot during formation airdrop. Overall the C-130J provides a higher potential for SA than the C-130H for individuals (namely the Pilot), but this improvement does not extend towards team SA. While the C-130J effectively compensates for the replacement

of the Navigator and Engineer in the airland mission, it actually has lower team SA during the formation airdrop than the C-130H despite the legacy aircrew working harder.

Finally, the relationship between SA and workload model outputs was examined for potential trends. In the formation airdrop scenario, the relationship between workload and SA was highly dissociated and did not reveal any trends. This corresponds well to Endsley's SAGAT test data (1993). However, the airland scenario revealed that SA could be maintained at a high level (albeit with a large variance) until workload increases to a large level. This corresponds to Endsley's theoretical SA-workload function (II. Literature Review, Figure 5) from her same 1993 study.

Significance of Research

Situation awareness is of prime importance to tactical and combat aviation, however measuring it typically occurs with prototypes, test articles, and real operators after the aircraft has been designed or even built. Perhaps of greatest significance to the research community is the development of a predictive workload algorithm that distinguishes between tactical SA and strategic SA and attempts to measure total SA in team settings of different sizes. While there have been limited previous attempts to model SA potential with discrete-event simulation, this thesis presents the most detailed analysis to deterministically predict SA and distinguish its origins between task-centric tactical SA and workload-limited strategic SA.

Because this study compares a four person cockpit crew of the C-130H with a more automated, two-person cockpit crew of the C-130J, it examines how workload and resultant SA changes when a human is removed from the cockpit and replaced with

automated systems. Predictive analysis of this phenomenon was not possible a generation ago when debates raged over reducing airline cockpits to a two-person affair. The research presented here confirms anecdotal evidence that the benefits of one system over the other depends on circumstance. The impact of removing two crewmembers from the cockpit and replacing them with automation has mixed results in both workload and situation awareness. This is probably not what the systems engineers intended when designing the C-130J.

The scenarios examined here are a staple of tactical airlift, both in training and in combat. While comprehensive data was not publicly available at the time of this writing, SKE formation airdrop represents approximately 35-40% of squadron-level tactical training and is typical in large exercises such as RED FLAG and the USAF Weapon's School Mobility Air Forces Exercise (MAFEX). More broadly, formation airdrop (both using SKE and visual procedures) may occur on up to 75% of training missions (Shinaberry, 2013). The Air Force mandates that pilots fly at least 12 SKE missions a year (AFI 11-2C-130, Vol 1, 2010). While formation airdrop (including the use of SKE) has been used in combat (Panama, 1989; Haiti, 1994; Iraq, 2014), based on this author's experience it represents perhaps less than 1% of deployed airlift missions. Single-aircraft airdrop missions were more prevalent in Afghanistan, reaching their peak in 2012. However, the mainstay of tactical airlift missions during Operations IRAQI FREEDOM and ENDURING FREEDOM has been single-aircraft airland. Perhaps 90% of airland missions in both theaters begin with some kind of tactical arrival as simulated in the Maximum Effort Airland scenario, with perhaps 30-40% of landings in Afghanistan

requiring maximum effort procedures. The remainder may use normal landing procedures or mix the two.

Further, while SA and workload affect each other, their correlation is not direct. In fact, the aircraft with higher workload also experienced higher total SA. This downplays the impact that sophisticated avionics would have on enhancing SA at all times. Put simply: it depends. However, this complex interplay between workload and SA further supports the complexity shown by Endsley (1993).

Recommendations for Action

Systems Engineers and cockpit architects should carefully consider task allocation and information available to the aircrew. Reducing the size of the cockpit crew must correspond with an appropriate redesign of procedures to accommodate a reduction in required tasks and cumulative workload. This analysis shows that a workload reduction in one mission does not necessarily translate to reduced workload in all missions. Since the C-130J's much more sophisticated avionics (with increased data available to the pilots) did not result in a guaranteed increase in SA, engineers must also consider that total SA is not simply reflective of the total quantity of data, but also how and when it might be used. Clearly, the autopilot and autothrottles are advantageous when used (SKE Formation Airdrop), but only for the Pilot. Workload, however, increased heavily when one of the operators had to manipulate a keyboard or write data, thus adversely affecting operators other than the Pilot. Designers must consider small choices, such as whether to use a switch, button, dial, or computer entry when manipulating aircraft systems. While

multi-function and heads-up displays provided much richer SA, their utility was best realized at low-level. Still, there is no substitute for looking out of the window.

Finally, designers must consider not only technical procedures in the checklists, but how the aircraft might be employed operationally. This thesis included lookout doctrine, intra-cockpit communication, tactical employment, and procedures developed at the operational level into both workload and situation awareness analysis. The feedback from other crewmembers both added to workload and situation awareness which benefited the C-130H. Thus, operators should continue to learn how to best exploit the strengths of the systems design and provide copious feedback to avionics and cockpit designers to iterate the design process.

Recommendations for Future Research

Since predictive SA modeling is an immature science, further experiments are needed to validate the novel approach taken here. Ideally a SAGAT or other similar objective SA measurement technique could be used to validate this experiment's output. Specifically, experiments are required to determine which tasks add to tactical SA, by how much, and if it is possible for a task to detract from tactical SA. Another study into tactical SA should be conducted. Another survey should be produced which explains tactical versus strategic SA, quantity/quality of information versus priority of information, and opportunity costs versus incorrect SA. The rating scale should very carefully explain negative SA scores and consider not including them at all. Phases of flight may require more detail than cruise, airdrop, or airland, as SA values may change

with altitude, proximity to objective area, or other mission factors. Also, more survey respondents should be used in a future survey in order to reduce variability.

The thresholds for high, medium, and low strategic SA should be established experimentally as well as the cognitive workload required to maintain strategic SA. The relative weight of strategic and tactical SA on total SA requires further study. While this experiment seeks to model Level 1 SA some tasks in both networks included a component of evaluation (i.e. evaluate aircraft performance, “is aircraft safe to drop?” etc), Level 2 and Level 3 SA could potentially be simulated in future experiments. Further research should look into possible methods to predicatively model higher SA levels.

Team SA, as described in this thesis, may be the first and best existing attempt at quantifying such a complex concept, but it still leaves much to be desired. Further research should be devoted towards understanding and capturing the complex interactions between team members in order to build collective team SA. While the current method of setting team SA equal to the individual with the highest SA, this ignores how the information is shared between individuals on that team and how their attention is prioritized, which effectively eliminates any positive contribution from lower SA individuals. Further research should seek to establish a measureable relationship between individual SA and SA for the collective team.

The experiments described in this thesis are based on “normal” operations. That is, a baseline scenario with few perturbations and no abnormal situation or unanticipated change. These baseline models could be manipulated to introduce unanticipated changes such as in-flight emergencies, threat reactions, and off-course maneuvering. For example,

how would automation affect workload and situation awareness during formation airdrop or maximum effort airland differ when unanticipated change or abnormal situations are introduced? Further studies could examine other C-130 missions as described in Appendix A: Description of C-130 Aircraft.

Finally, to what extent does automation reliance have in terms of mission effectiveness and performance (beyond workload and situation awareness directly) versus a legacy system with larger crew compliments? Drop accuracy and time over target data are regularly collected by operational units. Subjective evaluations from exercises and after action reports could be qualitatively analyzed to compare C-130J and C-130H performance. Further analysis must be conducted to determine how automation, workload and SA affect those results instead of individual proficiency level or other factors.

Summary

This thesis describes a novel method to predict aircrew situation awareness in an attempt to determine the effects of automation on aircrew workload and situation awareness during two specific tactical airlift missions. The analysis results indicate that automation generally reduces workload and increases situation awareness, especially for the Pilot, but results are somewhat mixed and highly dependent on scenario and crew position. The significance of these results (and the novel methodology) are discussed, as well as recommended actions. Finally recommendations for continued research are made: chiefly, validation of the predictive situation awareness methodology via

experimentation and running similar discrete-event simulations with unanticipated abnormal situations injected to force aircrew reaction.

Appendix A: Description of C-130 Aircraft and Missions

C-130 Roles and Missions

As a tactical airlifter, the primary mission of the C-130 is movement of cargo and passengers over relatively short distances (i.e. intra-theater) via airland (landing on established runways and landing zones) or airdrop (parachute delivery to a drop zone). Cargo may consist of loose items, vehicles and rolling stock, or palletized cargo that interlocks into rails located on the left and right side of the cargo compartment. The C-130 can simultaneously carry both passengers and cargo in both airland and airdrop roles and quickly off-load them through a rear-loading ramp and side-facing paratroop doors. Rollers mounted to the cargo floor allow for easy roll-on/roll-off of cargo pallets and the cargo compartment can be quickly reconfigured to accommodate a new load.

The C-130 can accomplish a wide variety of special mission sets in both modified and unmodified aircraft. Aeromedical evacuation of wounded patients requires is a common mission performed with regular C-130s in combat zones. Selected Air National Guard and AF Reserve units perform specialized airborne firefighting services with the Modular Airborne Fire Fighting System (MAFFS): a roll-on/roll-off pallet train and specialized training in MAFFS employment. Antarctic resupply is accomplished on ice runways with ski-equipped LC-130H aircraft from the New York Air Guard. The Air Force Special Operations Command (AFSOC) employs highly modified C-130 aircraft to perform close air support (CAS) and interdiction fires, infiltration/exfiltration of special operations forces, helicopter and tilt-rotor air refueling. C-130s have also been tasked for

search and rescue (SAR), served as radio relays, electronic warfare platforms, and command and control assets. However, the bulk of conventional C-130 missions are airland and airdrop, both in formation and as a single aircraft.

The C-130J, with its two-person cockpit (Pilot and Copilot) relies on a modern glass cockpit and automation to replace the duties performed by the Navigator and Engineer found on the C-130H. The C-130J avionics are capable of automatic systems monitoring and provide both an enhanced quantity and quality of data available to the aircrew. The C-130J avionics system is radically different than the C-130H. The H-model "steam gauges" of analog round-dial instruments are replaced by pilots' heads-up displays (HUD), color multi-function displays (MFD), and an upgraded mission computer and software. This mission computer (Communications, Navigation, Intercom-Multipurpose Unit, or CNI-MU), monitors aircraft systems health, plots the navigation solution, controls the primary flight displays (MFD and HUD), tunes radios, manages, provides circuit protection, controls defensive system settings, computes performance data, and manages station keeping (SKE) formation parameters (TO 1C-130J-1, 2009). All of this is done through a keyboard and monochromatic interface. Conversely, the Self-Contained Navigation System (SCNS) in the C-130E/H primarily plots the navigation solution and tunes radios (TO 1C-130H-1, 2010). Prior to the SCNS upgrade in the 1990s, the C-130 depended heavily on having a pilot tune each radio separately and a navigator manually plotting position and manipulating the aircraft steering solution. Both SCNS and the CNI-MU function as a Flight Management System (FMS) to varying extents: the CNI-MU integrates more sensors and performs more function than SCNS.

Because so many features are built into the CNI-MU's control layers, the C-130J eliminated dozens of mechanical circuit breakers, analog gauges, and switches. Some of these circuit breakers were located outside of the cockpit, and some functions, such as loading cryptographic data into radios required the copilot to crawl under the flight deck ladder or scramble through the cargo compartment in order to load. Systems monitoring moved from the Flight Engineer to the aircraft, and many switches and gauges located on the C-130H navigator station and overhead panel (even out of the pilots' reach) were consolidated into the CNI-MU or moved to be within reach of the pilots (TO 1C-130E(H), 2009; TO 1C-130H-1, 2010; TO 1C-130J-1, 2009). While MFDs are manipulated via the CNI-MU and other soft-keys surrounding them, the C-130H utilizes more toggle switches, push buttons, and dials to manipulate the cockpit.

Each aircraft presents information differently. The color MFDs can be customized to the pilot's preference, whereas analog gauges have a very limited ability to display different data. Analog gauges may use some logic to trip a warning light when an operational limitation is exceeded, or they may have a painted marker defining a normal operations range. Unless there is a warning light to capture the operator's attention, it is entirely incumbent upon that operator to identify when a system has malfunctioned. In the case of a loss in propeller hydraulic fluid ("Prop Low Oil" light), a warning light illuminates on the engine instrument stack to indicate that any one of the four propellers is losing fluid, but the Copilot or Engineer must look to the Copilot's side shelf to identify the problematic propeller (TO 1C-130H-1, 2010; TO 1C-130(K)H-1, 2010). The C-130H3 includes Mode Advisory, Caution and Warning System (MACAWS) panels which track multiple system parameters, consolidate warning lights in fewer locations,

and alerts the aircrew with a flashing “Master Caution” when certain MACAWS alerts are triggered(TO 1C-130(K)H-1, 2010). While this serves to call greater attention to malfunctions, MACAWS treats major and minor malfunctions with the same level of primacy. This can be distracting when a relatively minor malfunction diverts attention during critical phases of flight.

The C-130J integrates even more systems monitoring than the C-130H3. Alerts are generated by the mission computer and cued on the HUD (TO 1C-130J-1, 2009). This draws the pilots’ attention to one of the MFDs for the computer-diagnosed problem. The pilots can thus run a checklist that shares the same name as the computer-diagnosed problem, versus staring at a series of instruments and gauges and manually deducing the origin and name of the problem (Shinaberry, 2013). Therefore, a pilot could theoretically all but remove systems monitoring from their instrument scan.

Because of the size and complexity of the C-130H cockpit, several instruments are hidden by the flight controls. Even the SKE Plan Position Indicator Scope occupies a significant portion of the center windscreen and obscures forward visibility (TO 1C-130E(H), 2009). The C-130H3 and C-130J incorporate the SKE display into existing glass displays. Since MFDs and other “glass cockpit” displays can incorporate more complex data displays and layer that data, a significant number of gauges disappeared from the pilots’ instrument panel, resulting in a “cleaner” appearance and fewer places to search for information.

C-130J airdrops are primarily automatic, computer-releases, whereas C-130E/H is capable of a computer-released airdrop, but it is almost always done manually. That is, one of the pilots must actuated the “green light” and ADS button (if applicable) at the navigator’s “green light” call. Furthermore, because pre-SCNS C-130s did not have a computer-derived Computer Air Release Point (CARP), C-130H crews extensively rely on the navigator to manually determine a preflight CARP and update the SCNS CARP during the mission. As a result, the navigator can verbally direct the pilot to make adjustments to the CARP based on last minute observations in ballistics. This judgment skill allows the navigator to command “green light” visually by manually sighting the desired point of impact against a known reference in the aircraft and using timing (AFI 11-231, 2005). While the C-130J can drop visually at extremely low altitude, regular employment of these “sight-angle” drops are largely unique to the legacy C-130H. Frequently, the only known data points in the ballistic wind profile are surface winds reported by the drop zone and the winds sensed by the aircraft at drop altitude. Because this can lead to errors in ballistic data, the C-130H navigator can make adjustments based on visual cues such as smoke or correct from prior strike reports, whereas the C-130J pilots are very reluctant, if not restricted from making slight windage adjustments (Shinaberry, 2013). Also, any changes to the Point of Impact (target on the DZ) or major CARP adjustments require reprogramming the navigational solution. Manipulating the mission computer (SCNS or CNI-MU) drives significant workload for the operator assigned to it (pilot not flying in the C-130J or the C-130H navigator). However, in some cases, changes in PI can be handled quicker in the C-130H because the aircrew can rely on visual means to manually release the airdrop load, but the C-130J must reprogram the

CNI-MU to accommodate dependence on computer guidance and release (Frampton, 2009). Although, as the C-130J matures, tactics to drop visually and improve responsiveness are being developed (Frampton, 2009).

Parachute drops are very sensitive to wind due to their extended time of fall compared to an object falling purely ballistically (such as a bomb). Thus, minor variations caused by DZ reporting error, old data, or low level wind shear have measurable effects on accuracy. While a purely computer-derived drop is more likely to drop with the same or higher accuracy when ballistic wind data is good, when the input data is poorer quality, the human operator must use judgment to apply a correction factor. C-130H aircrews do this routinely, and while a C-130J aircrew could also apply a correction factor, in practice they adhere strictly to computer-generated CARPs, provided that data is judged reasonable and safe (Kennedy, 2015; Shinaberry, 2013).

Because the C-130J's autopilot and autothrottles can be coupled Computed Aircraft Positioning System (CAPS) SKE formation position, the aircraft can be flown in formation enroute through the drop completely on autopilot. The C-130H, however, is not equipped with autothrottles, and the SKE formation must be flown manually based on a scope return and gauge needles. Once exception: the C-130H Pilot could engage "altitude hold" on the autopilot, while manually flying lateral and longitudinal position with the control yoke and throttles.

The C-130 Avionics Modernization Program (AMP) represents another significant overhaul of C-130H cockpits to include a glass cockpit, new radios, data-links, FMS, air data system and even a HUD to improve mission capability and ensure future compliance with communications, navigation and air traffic management required

to operate in high-density airspace, such as Europe (Nelson, Dunavold, & Dickson, 2010). Converting all C-130Hs to the AMP standard would eliminate differences training and qualifications to aircraft that are superficially similar (for instance, the author was required to maintain differences training and separate qualifications on the C-130E, H1, H2, and H3 aircraft simultaneously)(GAO, 2014). AMP aircraft replaced analog gauges from the C-130H with six color MFDs, a FMS, pilot and copilot HUDs, and new system alerting interfaces. The AMP represents a major upgrade to the avionics architecture while retaining legacy SKE, propulsion and most other systems, while automating the position of navigator yet retaining the flight engineer. While the AMP has not been operationally fielded to the C-130H fleet (due to costs and widespread conversion to the C-130J), test results reinforce the demands of tactical aviation: formation flying, low level terrain avoidance, and frequent time and course adjustments to respond to airspace and threats.

Figure 35: C-130 AMP cockpit(GAO, 2014)

Test results showed a satisfactory performance of SKE enroute and airdrop without a navigator present, yet airspace and terrain display data limitations caused an unsatisfactory increase in workload and poor time control performance using the available FMS. Furthermore, flight management duties, such as route changes (i.e. off course maneuvering and flight plan modifications) and time control resulted in unacceptably high workloads due to poor automation of navigator functions (Nelson, Dunavold, & Dickson, 2010). Further studies conducted by the Government Accountability Office showed that while the C-17 and C-130J do not include the navigator, certain airlift and combat missions are augmented with a third pilot. Thus, if workload overburdens a two-pilot cockpit to the point where a third pilot is required to

mitigate workload, the savings offset by removing the navigator from the aircraft are significantly offset (GAO, 2014).

The C-130 AMP tests were conducted as tactical training missions using both visual and SKE formation airdrops, both in leader and wingman positions, employed with C-130H procedures. Test aircrew evaluated workload using the Bedford scale (similar to the Cooper-Harper scale) and a post-mission interview with a human factors expert (Nelson, Dunavold, & Dickson, 2010). During these tests, it was found that the AMP could attain a time over target (TOT) within required tolerances, but only with considerable pilot effort. During most phases of flight, the flight engineer workload was satisfactory with enough time to complete primary and additional tasks. In many phases of flight the pilots reported instances where workload was tolerable and only a small amount of time was available to complete additional tasks. However for the lead aircraft in formation during airdrop, cruise, and general formation flight created some instances where workload was marginally possible with minimal time remaining for additional tasks(Nelson, Dunavold, & Dickson, 2010).

While some of the higher workload ratings were to be expected (task demands of coordinating with air traffic control, for example), the requirement to plot and avoid threats, make subsequent adjustments to time control in order to meet a desired TOT drove workload to unacceptable levels. Primarily this was due to the requirement to program the FMS with each required changed coupled with the FMS' inability to accommodate multiple complex parameter changes (altitude, speed, course). Furthermore, the test participants reported high levels of workload associated with the mission that was shared between legacy C-130H and AMP aircraft. Specifically, the

simultaneous demands during a SKE airdrop to send SKE commands, monitoring and making radio calls, obtaining clearances, completing checklists, searching for and visual evaluation of the drop zone, setting up the navigation solution, and wingman considerations (Nelson, Dunavold, & Dickson, 2010).

Technology, such as Missile Warning Systems (MWS) and Radar Warning Receivers, exist on both the H and J to detect threats, and in some instances, dispense countermeasures, but aircrew are trained and expected to augment these systems in both threat detection and reaction. One advantage the C-130J has is the incorporation of threat symbology in the HUD, whereas the C-130H crew must look inside the cockpit to determine the source of the threat. However, with increase speed of recognition comes a trade in dependency and fixation on the HUD's limited field of view—neglecting scanner duties in positions other than 12 o'clock (Burgess, 2005; Kennedy, 2015; Shinaberry, 2013).

Appendix B: Detailed Scenario Narratives

Scenario 1: Station Keeping Equipment (SKE) Formation Personnel Airdrop

A formation uses Station Keeping Equipment (SKE) to maintain formation position when conditions do not permit visual formation procedures and can be quite large (up to 36 airplanes on a single channel) (TO 1C-130H-1, 2010; TO 1C-130(K)H-1, 2010; TO 1C-130J-1, 2009). Flying SKE has a rather extensive set of "contracts" that aircraft maintain with each other(AFTTP 3-3.C-130E/H, 2010; AFTTP 3-3.C-130J, 2010; AFI 11-2C-130, Vol 3, 2010). These contracts include allowable deviations in airspeed, altitude, heading, and position error over the drop zone. Over the drop zone alone, the formation and element lead aircraft each have a maximum cross-track deviation and a timing window, and the wingman and element lead aircraft have a maximum formation (track-while-scan) lateral deviation (AFTTP 3-3.C-130E/H, 2010; AFTTP 3-3.C-130J, 2010). Finally each element drops 50 feet higher than the preceding element to ensure parachutes do not contact following aircraft (AFI 11-2C-130, Vol 3, 2010).

Because it has the most restrictive contracts, element lead in a SKE formation is considered one of the more difficult formation positions to maintain in the C-130H, especially when over the drop zone. Element lead must maintain his formation position relative to the formation lead, maintain positional awareness of the wingman in front of him (if the preceding wingman drifts back too far, he is a conflict with element lead), manually relay SKE computer commands via push button on the Flight Command Indicator (FCI), while maintaining a stable platform for his wingman and following

element. However, CAPS (Coordinated Aircraft Positioning System) coupled to the autopilot and autothrottles has largely relieved the C-130J crew of manual formation position maintenance and sending most FCI commands (TO 1C-130J-1, 2009).

C-130J pilots have described an easier ability to maintain an accurate formation position. C-130E/H crews describe SKE as flying an hour-long ILS (precision instrument approach) because of the concentration of chasing and centering multiple needles (Delgado, 2014; Shinaberry, 2013; Kennedy, 2015; Pedersen, 2015). The C-130J uses CAPS (Coordinated Aircraft Positioning System), which can be coupled to the autothrottles(TO 1C-130J-1, 2009). Even C-130J formation slowdowns (i.e. slowing from enroute airspeed to drop airspeed) are normally done with autothrottles (AFTTP 3-3.C-130J, 2010). SKE must be manually hand-flown in the C-130H (exception: can use only altitude hold function of the autopilot) (TO 1C-130H-1, 2010; TO 1C-130(K)H-1, 2010).

On C-130H aircraft, crews fly SKE formation positions by referencing a Plan Position Indicator scope (PPI) (large stand-alone CRT on top of pilots' instrument panel of E/H1/H2 or AN/APN-241 radar display mode for upgraded H1/H2 aircraft and all H3 aircraft). The PPI displays a circle blip for the lead aircraft and a square blip for all other SKE formation members Also, SKE airplanes have a Track While Scan (TWS) function that shows formation position with mechanical needles. Left and right cross track deviation take the place of the pilots' flight director, a vertical deviation carat is in lieu of glide slope indication, and a stand-alone in-track deviation/range. TWS works in conjunction with the PPI to aid the pilot in maintaining formation position (TO 1C-130H-1, 2010; TO 1C-130(K)H-1, 2010).

CAPS displays other SKE formation members as separate aircraft shapes in plan view on a Heads-Down-Display which, unlike the C-130H PPI (including H3, can also overlay flight planned route, other airborne traffic, tactical information and other navigational information on the same screen. The pilot can incorporate CAPS symbology into the Heads-Up-Display (HUD), and has new symbology not available to the C-130H pilot: speed carets, desired path box (TO 1C-130J-1, 2009). The C-130J presents “fly-to” symbology in addition to deviation symbology (i.e. the cross-track, elevation and range deviation needles on the C-130H1). CAPS enables 35 degrees of bank coupled to autopilot (TO 1C-130J-1, 2009), thus removing the hard bank angle limit of 20 degrees imposed on formation and element leaders in the C-130H(AFI 11-2C-130, Vol 3, 2010).

A significant part of SKE procedure and training is how to execute turns, climbs, descents, airspeed changes, and airdrop as a formation. The SKE computer is capable of transmitting and receiving simple commands through the Flight Command Indicator (FCI) panel. The C-130H Navigator and Pilot share FCI tasks, where CAPS automatically sends most FCI commands in the C-130J. SKE (C-130E/H) requires two preparatory commands (at 30 and 5 seconds to go) and one execute (“E”) FCI command, range, and true airspeed for a computer turn. A properly formatted SKE computer turn command from the lead aircraft automatically starts a timer in the wingman’s SKE computer to command the wingman to turn over the same geographic point as lead. Furthermore the TWS needle transitions from cross track deviation to commanding a bank angle to maintain formation position in the turn. (TO 1C-130H-1, 2010; TO 1C-

130(K)H-1, 2010). As the wingman approaches the rollout point the TWS needle returns to cross track deviation.

CAPS (C-130J) can automatically send SKE commands to wingman C-130J aircraft or manually push SKE commands to C-130H aircraft (AFTTP 3-3.C-130J, 2010). A C-130J SKE formation is primarily flown with autopilot and autothrottles engaged (AFTTP 3-3.C-130J, 2010). Since there are continuously computed "fly-to" commands on the HUD and on the CAPS display, and CAPS automatically sends position commands, there are considerably fewer procedures for flying SKE with CAPS. This is manifested in C-130 Initial Qualification courses. While both the C-130H and C-130J both devote six simulator events to SKE training, the C-130H requires at least three SKE missions performed in the aircraft versus only one SKE mission for the C-130J (Delgado, 2014).

The workload impact of manually sending FCI commands have been described by pilots as significant (Kennedy, 2015; Shinaberry, 2013; Delgado, 2014). While enroute the Navigator relays initial commands (30 seconds before execution) and any numerical information (such as wind/drift information, altimeter settings, etc.). The Pilot (C-130H) relays "5 second" and "execute" commands while flying the aircraft. Nowhere is this workload more apparent than the slowdown, airdrop, and escape sequence. After the Navigator relays "30 seconds to slowdown" via the FCI, the Pilot is responsible for the next nine FCI commands until completion of the escape maneuver. This slowdown-drop-escape sequence involves a significant change in airspeed, descent to drop altitude, aircraft configuration, precise formation and course maintenance, numerous checklist

responses, and radio calls. This shift in FCI tasks to the Pilot occurs during an already high-taskload phase in the mission.

In order to execute airdrops in inclement weather, C-130E/H formation and element lead aircraft are required to be equipped with AWADS (Adverse Weather Aerial Delivery System) and trained in order to guide "dumb" (non-AWADS) wingmen across a drop zone(AFI 11-2C-130, Vol 3, 2010). AWADS is a high-resolution ground mapping radar (i.e. the AN/APN 241 low power color radar) that requires the navigator to analyze multiple radar targets and update the navigational solution to fine tune system position on the terminal leg for the airdrop.   Because C-130E/H aircraft were initially equipped with the lower resolution AN/APN-59 radar (which is only viewable at the navigator's station when the SKE PPI is installed), AWADS was considered a special qualification and dependent on having precision radar-equipped aircraft available. However, the C-130J is equipped with the AN/APN-241 radar as standard, and since it is intended to automatically guide the aircraft to the release point and automatically drop, AWADS-like capabilities are already build into the aircraft and the special-qualification is superfluous. Thus, provided that the aircraft's navigation solution is "tight," no update is required(Delgado, 2014).

Instead of a separate SKE Control Panel blocking copilot lower windows, the CAPS/SKE controls is integrated into the CNI-MU (Communication/Navigation/ Identification-Management Unit) interface pages. The SKE Control Panel uses rotary thumb wheels and push buttons as a user interface and is only accessible to the copilot, while the CNI-MU uses a keyboard and is the same primary interface used for most avionics data manipulation. Both interfaces control formation parameters (range, lateral,

and vertical position), designation of the leader and other formation members, SKE frequency, clock synchronization, and proximity alarm settings. While legacy SKE provides the crew with a proximity alarm if another formation aircraft is closer than a user-defined value CAPS will sound the proximity alarm if the closure rate with another formation aircraft is judged to be excessive or another aircraft is inside the user-defined proximity range(TO 1C-130H-1, 2010; TO 1C-130J-1, 2009).

This scenario twenty minutes before the formation leader's time over target (TOT) to the drop zone (DZ) with the "20 minute advisory" and the beginning of the Preslowdown Checklist. Throughout the scenario, the pilot and navigator (C-130H) or CAPS (C-130J) is relaying required SKE FCI commands. The formation begins at an enroute altitude and airspeed and must initialize a descent, then execute a turn to align with the DZ axis over the initial point (IP). Proper alignment is to ensure the entire "stick" of paratroopers land along the long axis of a rectangular DZ. After completion of the turn at the IP, the Copilot must reset the lateral position in the SKE Control Panel (C-130H) or CNI-MU (C-130J). Then, the formation slows from enroute airspeed to drop airspeed (Slowdown Checklist) then descends to drop altitude. The C-130H Navigator performs terminal AWADS updates to tighten the navigational solution. The Pilot fine tunes formation and navigation position closer to the DZ and the crew verifies that the aircraft has met all formation airdrop contracts and is in a safe position to drop.

When the aircraft reaches the Computed Air Release Point (CARP), the Navigator (C-130H) or Copilot (C-130J) calls for "green light," the troop jump light is illuminated, and the jumpers exit the aircraft (Release Point Checklist). The aircrew then delays to allow follower aircraft before climbing and executing the formation escape maneuver.

This scenario ends with the formation established at enroute airspeed and altitude and the Completion of Drop checklist finished.

Scenario 2: Maximum Effort Airland

A penetration descent is achieved by reducing power to idle at a precisely calculated distance and diving at high speed to a desired configuration altitude. The aircrew might plan to use the penetration descent to one of many high-speed, low altitude tactical arrivals, each with their own entry and exit parameters. Either at configuration altitude or during a low altitude tactical arrival, the aircraft must level off and slow down to lower gear and flaps. When approach speed is reached, the aircraft makes a steep final approach to the runway. Ideally, the throttles would remain at idle from enroute altitude until less than one nautical mile from landing.

In many parts of Afghanistan, Air Traffic Control (ATC) radar coverage is non-existent and consists only of the “tower” or LZ control team. Aircraft avoid each other procedurally using a coded position report. Traffic avoidance and terrain clearance is at the pilots’ own risk and ATC can only give advisories of other known aircraft that have checked in on that given frequency. The aircrew must avoid tactical Restricted Operating Zones (ROZ), high terrain, and weather. There may be no useable instrument approach, yet cloud layers from a passing thunderstorm require negotiation.

Remote FOBs may have short (as little as 3000 feet, or about a third the length and width of a normal runway), narrow, or unpaved, landing zones (LZ) that require maximum effort (assault) procedures(AFI 11-2C-130, Vol 3, 2010; AFI 11-2C-130J, Vol 3, 2009; AFI 13-217, 2007). The LZ may have a significant uphill/downhill gradient or

even a hump. Frequently, the runway is gravel or dirt or is in fair to poor condition. This type of landing is done at speeds below normal approach and landing speeds (with reduced stall margins) and touchdowns in a zone as little as 500 feet long (~2.5 seconds of flight time) and lit by only five infrared lights (AFI 13-217, 2007). The increased level of precision upon landing drives a more stabilized approach (i.e. tighter parameters) and is less forgiving than landing on a 10,000 foot long runway common at many Air Force bases. This forces the crew to maintain a carefully controlled, but aggressive descent profile, and it highlights the difference made by incorporating a heads-up display (HUD).

First, a configuration or ingress (if using a random tactical approach) altitude is chosen. From this altitude, a final approach point (point where aircraft descends from configuration altitude with landing gear and flaps extended) and minimum slowdown distance is determined. These two distances are manually calculated from established rules of thumb or extracted from tabulated data. The altitude to lose from enroute altitude to determines the length of the high-speed penetration segment. This is calculated by rules of thumb, tabulated data, or charts from the aircraft performance manual. The length of the penetration segment is added to the slowdown distance and final approach segment to obtain the total approach length. This number is adjusted for aircraft weight, winds aloft, terrain, and airspace considerations (AFTTP 3-3.C-130E/H, 2010; AFTTP 3-3.C-130J, 2010).

The C-130H aircrew manually calculates several altitude vs. distance "gates" (Figure 12) and compares SCNS (Self Contained Navigation System) distance-to-go and altimeter against are determined to evaluate energy management. The Navigator programs the final approach glideslope into SCNS which aides the Pilot in determining

energy and aim point on the LZ touchdown zone. While there are many techniques to manipulate SCNS and evaluate the energy state, this data is displayed only as course deviation and distance on the Horizon Situation Indicator and as raw numerical data on the SCNS control panels located outside of the normal field of view from the pilots' instrument panel. The C-130J aircrew enters a computed flight path angle into the CNI-MU (Communication/Navigation/Identification-Management Unit), which is displayed on the flight director and heads-up display (HUD). Based on current descent performance, the navigation display will show where the aircraft will arrive at the programmed altitude on the flight plan route. While SCNS will provide a numerical output for the winds experienced at that moment, the CNI-MU will apply wind-correction logic to the flight path. If the pilots' input a waypoint for the slowdown point, then the CNI-MU will calculate the vertical error to that waypoint, thus providing a real-time evaluate the aircraft's energy state (AFTTP 3-3.C-130J, 2010).

If the aircraft is descending too rapidly (ahead of profile) then the pilot may glide at a slower airspeed, proceed on a more direct routing to the LZ, or, as a last option, add power. If the aircraft is not descending quickly enough (behind profile), the pilot must choose a more indirect routing (adding travel distance), slowdown and configure the aircraft at a higher altitude, or change the type of tactical arrival (i.e. overhead pattern instead of high-speed straight-in).

Finally, on final approach with the LZ in the HUD field of view, the HUD flight path vector shows exactly where the aircraft is pointing, thus enabling an instantaneous decision whether or not the aircraft can make the LZ or will overshoot and go around. While C-130H pilots must visually evaluate the aircraft aim point on the LZ touchdown

points using the relative motion of the runway against the window, the C-130J HUD flight path vector precisely shows where the aircraft is going.

This scenario starts with the autopilot engaged and the aircraft at enroute altitude and airspeed some distance away from the landing zone (LZ). The pilots calculate penetration descent data for the airfield. The Copilot contacts air traffic control (ATC) to obtain latest weather conditions. The Navigator (C-130H) or Copilot (C-130J) makes updates the navigation solution to the landing runway and informs the tactical airspace controller and is released to ATC control. The Engineer (C-130H) calculates by hand, or Pilot/Copilot (C-130J) enter into the CNI-MU, takeoff and landing data (TOLD). The non-flying pilot checks the TOLD accuracy. After briefing the approach and landing, the Pilot calls for the Descent checklist.

Then the Pilot reduces the throttles to flight idle and begins a high-speed descent as close as possible to the airfield, circumnavigating the largest mountains visually with the help of the Copilot, Navigator (C-130H), or moving map displays. Both pilots evaluate the aircraft energy state and make corrections (lateral or vertical), as necessary, to maintain or regain the appropriate descent profile. ATC may desire periodic position reports and identify air traffic that the aircrew must avoid. At the calculated slowdown point, the Pilot levels the aircraft, while keeping the throttles at idle, commands for flaps “on speed” (incrementally lowering flaps at their design limit speed), gear, and the Before Landing checklist. When the LZ is visually identified, the Copilot reports “Field in sight” to ATC and requests permission to land.

On final approach the aircrew flies a steep 6-9 degree glide slope (compared to 3 degrees for a commercial airliner) until 150 ft, then adds power and reduces descent rate.

The Copilot advises the Pilot where he assesses the aircraft aim point is (left/right, long/short) and airspeed deviations (5 knots fast/3 knots slow). The Navigator (C-130H) reads radar altimeter settings to the Pilot in the last 50 feet, while the Copilot states sink rate and airspeed as the Pilot's scan transitions entirely outside. The aircraft touches down firmly inside the marked 500-foot long touchdown zone and the Pilot moves the throttles from flight idle to ground idle. After a quick verification from the Copilot of true airspeed (C-130J) or from the Engineer that there is no propeller malfunction, the Pilot, applies maximum braking and reverse thrust while slowing the aircraft to taxi speed.

During the ground roll, the Pilot reaches the tiller wheel and transfers control of the yoke to the Copilot. Meanwhile, the Loadmaster, upon command from the Pilot, opens the cargo ramp and door and prepares for the engines-running offload (ERO) as the Pilot executes a 180 degree turn in the pothole-riddled ramp on the far side while the rest of the crew assists the Pilot to avoid the ditch and numerous obstacles parked on the confined ramp. After setting the parking brake, the Loadmasters offload old cargo and upload new cargo while the Engineer (C-130H) or Copilot (through the CNI-MU—C-130J) computes TOLD. Maximum effort TOLD includes takeoff ground run, acceleration-check time, refusal speed, maximum effort takeoff speed, Fifteen minutes after landing, the offload and subsequent upload and ERO checklist is complete. The Pilot taxis to the runway then calls for the Before Takeoff checklist while the Copilot obtains a departure clearance.

Appendix C: Situation Awareness Task Assessment

Situation Awareness Task Assessment

Name: _________________________________ Airframe(s)/MDS: ____________ Crew Position: __________

Please rate the following generic aircrew tasks according to their effect on situation awareness (SA) for the operator performing those tasks. Consider whether the following tasks increase or decrease SA compared to a hypothetical state where the operator has his/her eyes closed. Columns are provided for three phases: normal cruise, airdrop, and airland mission events. SA is the operator's perception (or mental model) of elements in the environment around him/her within a volume of space and time, the comprehension of their meaning, and the projection of their status into the future[1]. Note: SA should not be misconstrued with the workload associated with that task.

Rating scale: -----------------Degraded------------------Neutral------------------------------Improved-------------------------------

Significant	Noticeable	Slightly	No Effect	Slightly	Noticeable	Significant
-3	-2	-1	0	+1	+2	+3

	MISSION EVENT:	CRUISE FLIGHT	FORMATION AIRDROP	ASSAULT LANDING
1	Reading instrument or gauge			
2	Reading MFD/moving map/digital display			
3	Viewing Head's Up Display (HUD)			
4	Looking out of window			
5	Reading raw computer data			
6	Radar/sensor interpretation			
7	Keyboard/data entry			
8	Writing (data cards, kneeboard, etc.)			
9	Reading charts, "sticks," approach plates			
10	Manual computations (whiz wheel, TOLD, tab data, etc)			
11	Talking, simple (advisory calls, responses)			
12	Talking, complex (briefings, radio calls, etc)			
13	Listening, simple (alerts, advisory call)			
14	Listening, complex (radio, crew feedback)			
15	Background listening (monitoring RWR, radio)			
16	Simple maneuvering (maintaining parameters)			
17	Complex maneuvering (defensive reactions)			
18	Simple button/switch actuation			
19	Cumbersome button/switch actuation			

Remarks:

[1] Endsley, M. R. (1988a). Situation Awareness Global Assessment Technique. *Proceedings of the IEEE 1988 National Aerospace and Electronics Conference: NAECON 1988. 3*, pp. 789-795. Dayton: IEEE.

Appendix D: Task Listings and Tactical SA Assignments

Table 28: Task Listing and Tactical SA for Basic Aircraft Control (C-130H)

Tac SA Value	Task ID	Function	Task
0	0	(Root)	START Flying
0	1_0	Basic Aircraft Control (C-130H)	START
0	1_1_0	Control the Airplane (P)	START
0	1_1_2	Control the Airplane (P)	Adjust throttles
0	1_1_3	Control the Airplane (P)	Move Rudder Pedals
0	1_1_4	Control the Airplane (P)	Move control yoke
0	1_1_5	Control the Airplane (P)	Wait
0	1_1_999	Control the Airplane (P)	END
0	1_2_0	Scan for threats (All)	START
0	1_2_10	Scan for threats (All)	Delay3
0.15/.2	1_2_11	Scan for threats (All)	Scan outside (E)
0	1_2_12	Scan for threats (All)	Call threat (N)
0	1_2_13	Scan for threats (All)	Call threat (P)
0	1_2_14	Scan for threats (All)	Scan outside (LM)
0	1_2_15	Scan for threats (All)	Dispense counter- measures (N)
0	1_2_16	Scan for threats (All)	Maneuver airplane (P)
0	1_2_17	Scan for threats (All)	Call threat (CP)
0	1_2_18	Scan for threats (All)	Call threat (E)
0.2	1_2_19	Scan for threats (All)	Monitor safety of flight (CP)
0	1_2_2	Scan for threats (All)	Report threat (CP)
0	1_2_20	Scan for threats (All)	Dispense counter- measures (LM)
0	1_2_21	Scan for threats (All)	Call threat (LM)
0.2	1_2_22	Scan for threats (All)	Monitor safety of flight (N)
0.15/.2	1_2_23	Scan for threats (All)	Scan outside (P)
0.2	1_2_24	Scan for threats (All)	Monitor safety of flight (E)
0.05	1_2_3	Scan for threats (All)	Listen RWR1
0.05	1_2_4	Scan for threats (All)	Listen RWR
0.15/.2	1_2_5	Scan for threats (All)	Scan outside (CP)
0.15/0.2	1_2_6	Scan for threats (All)	Scan outside (N)
0	1_2_7	Scan for threats (All)	Delay
0	1_2_8	Scan for threats (All)	Delay1
0	1_2_9	Scan for threats (All)	Delay2
0	1_2_999	Scan for threats (All)	END
0	1_3_0	Monitor Aircraft Performance (P)	START
0	1_3_1_0	Navigate the Airplane (P)	START Navigating
0.1	1_3_1_2	Navigate the Airplane (P)	Read stick diagram
0.15	1_3_1_3	Navigate the Airplane (P)	Monitor SCNS Distance to Go
0.15	1_3_1_4	Navigate the Airplane (P)	Monitor SCNS Xtrck
0.15	1_3_1_5	Navigate the Airplane (P)	Monitor Heading
0	1_3_1_6	Navigate the Airplane (P)	Monitor Ground Speed
0.1	1_3_1_7	Navigate the Airplane (P)	Ensure terrain clearance
0	1_3_1_8	Navigate the Airplane (P)	Calculate time status

0	1_3_1_9	Navigate the Airplane (P)	Routing
0	1_3_1_999	Navigate the Airplane (P)	END
0	1_3_10	Monitor Aircraft Performance (P)	Nothing
0	1_3_11	Monitor Aircraft Performance (P)	Calculate Pilot correction
0	1_3_12	Monitor Aircraft Performance (P)	Autopilot?
0	1_3_13	Monitor Aircraft Performance (P)	Delay
0	1_3_2_0	Formation Position (P)	START Formation Flying
0	1_3_2_2	Formation Position (P)	Calculate Pursuit Curve
0	1_3_2_3	Formation Position (P)	Calculate Closure velocity
0.15	1_3_2_4	Formation Position (P)	Monitor SKE in-track distance
0.15	1_3_2_5	Formation Position (P)	Monitor Elevation WRT Lead
0.15	1_3_2_6	Formation Position (P)	Monitor SKE Xtrack
0	1_3_2_7	Formation Position (P)	Routing
0	1_3_2_999	Formation Position (P)	END
0.15	1_3_4	Monitor Aircraft Performance (P)	Monitor pitch
0.15	1_3_5	Monitor Aircraft Performance (P)	Monitor airspeed
0.15	1_3_6	Monitor Aircraft Performance (P)	Monitor bank angle
0.15	1_3_7	Monitor Aircraft Performance (P)	Monitor altitude
0.15	1_3_8	Monitor Aircraft Performance (P)	Monitor Vertical velocity
0	1_3_9	Monitor Aircraft Performance (P)	Routing
0	1_3_999	Monitor Aircraft Performance (P)	END
0	1_4_0	Pilot Monitoring Duties (CP)	START
0	1_4_1_0	Navigate the Airplane (CP)	START Navigating
0.1	1_4_1_2	Navigate the Airplane (CP)	Read chart
0.15	1_4_1_3	Navigate the Airplane (CP)	Monitor SCNS Distance to Go
0.15	1_4_1_4	Navigate the Airplane (CP)	Monitor SCNS Xtrck
0.15	1_4_1_5	Navigate the Airplane (CP)	Monitor Heading
0.15	1_4_1_6	Navigate the Airplane (CP)	Monitor Ground Speed
0.1	1_4_1_7	Navigate the Airplane (CP)	Ensure terrain clearance
0	1_4_1_8	Navigate the Airplane (CP)	Calculate time status
0	1_4_1_9	Navigate the Airplane (CP)	Routing
0	1_4_1_999	Navigate the Airplane (CP)	END
0.15	1_4_10	Pilot Monitoring Duties (CP)	Monitor airspeed
0	1_4_11	Pilot Monitoring Duties (CP)	Autopilot?
0	1_4_12	Pilot Monitoring Duties (CP)	Delay
0	1_4_2_0	Formation Position (CP)	START Formation Flying
0	1_4_2_2	Formation Position (CP)	Calculate Pursuit Curve
0	1_4_2_3	Formation Position (CP)	Calculate Closure velocity
0.15	1_4_2_4	Formation Position (CP)	Monitor SKE in-track distance
0.15	1_4_2_5	Formation Position (CP)	Monitor Elevation WRT Lead
0.15	1_4_2_6	Formation Position (CP)	Monitor SKE Xtrack
0	1_4_2_999	Formation Position (CP)	END
0.15	1_4_4	Pilot Monitoring Duties (CP)	Monitor bank angle
0.15	1_4_5	Pilot Monitoring Duties (CP)	Monitor altitude
0.15	1_4_6	Pilot Monitoring Duties (CP)	Monitor Vertical velocity
0	1_4_7	Pilot Monitoring Duties (CP)	Provide Feedback to Pilot
0.25	1_4_8	Pilot Monitoring Duties (CP)	Evaluate Aircraft Performance
0.15	1_4_9	Pilot Monitoring Duties (CP)	Monitor pitch

0	1_4_999	Pilot Monitoring Duties (CP)	END
0	1_5_0	Navigate the Airplane (N)	START Navigating
0.15	1_5_10	Navigate the Airplane (N)	Monitor Heading
0.15	1_5_11	Navigate the Airplane (N)	Monitor Ground Speed
0.1	1_5_12	Navigate the Airplane (N)	Ensure terrain clearance
0.15	1_5_13	Navigate the Airplane (N)	Observe weather radar
0	1_5_14	Navigate the Airplane (N)	Autopilot?
0	1_5_15	Navigate the Airplane (N)	Delay
0	1_5_2	Navigate the Airplane (N)	Direct Pilot corrections
0	1_5_3	Navigate the Airplane (N)	Calculate time status
0	1_5_4	Navigate the Airplane (N)	Do nothing
0	1_5_5	Navigate the Airplane (N)	Routing
0.1	1_5_6	Navigate the Airplane (N)	Read chart
0	1_5_7	Navigate the Airplane (N)	Routing task
0.15	1_5_8	Navigate the Airplane (N)	Monitor SCNS Distance to Go
0.15	1_5_9	Navigate the Airplane (N)	Monitor SCNS Xtrck
0	1_5_999	Navigate the Airplane (N)	END
0	1_6_0	Monitor systems (E)	START
0	1_6_10	Monitor systems (E)	Do nothing
0	1_6_11	Monitor systems (E)	Autopilot?
0	1_6_12	Monitor systems (E)	Delay
0.05	1_6_2	Monitor systems (E)	Listen (P)
0.05	1_6_3	Monitor systems (E)	Listen (CP)
0.05	1_6_4	Monitor systems (E)	Listen (N)
0	1_6_5	Monitor systems (E)	Decide/Observe
0	1_6_6	Monitor systems (E)	Troubleshoot
0.15	1_6_7	Monitor systems (E)	Monitor Acft performance
0	1_6_8	Monitor systems (E)	Routing
0.15	1_6_9	Monitor systems (E)	Monitor system health
0	1_6_999	Monitor systems (E)	Report problem
0	1_7_0	Listen to Radios (All)	START
0.05	1_7_2	Listen to Radios (All)	Listen to Radios (P)
0.05	1_7_3	Listen to Radios (All)	Listen to Radios (CP)
0.05	1_7_4	Listen to Radios (All)	Listen to Radios (N)
0.05	1_7_5	Listen to Radios (All)	Listen to Radios (FE)
0	1_7_999	Listen to Radios (All)	END
0.05	1_9	Basic Aircraft Control (C-130H)	Listen (P)
0	1_999	Basic Aircraft Control (C-130H)	END
0	2_0	Basic Aircraft Control (C-130J)	START
0	2_1_0	Control the Airplane (P)	START
0	2_1_2	Control the Airplane (P)	Adjust throttles
0	2_1_3	Control the Airplane (P)	Move Rudder Pedals
0	2_1_4	Control the Airplane (P)	Move control yoke
0	2_1_5	Control the Airplane (P)	Wait
0	2_1_999	Control the Airplane (P)	END

0	2_2_0	Scan for threats (All)	START
0.2	2_2_11	Scan for threats (All)	Monitor safety of flight (CP)
0	2_2_12	Scan for threats (All)	Report threat (CP)
0	2_2_13	Scan for threats (All)	Dispense counter- measures (LM)
0	2_2_14	Scan for threats (All)	Call threat (LM)
0.15/.2	2_2_16	Scan for threats (All)	Scan outside (P)
0.05	2_2_18	Scan for threats (All)	Listen RWR1
0.05	2_2_19	Scan for threats (All)	Listen RWR
0.15/.2	2_2_20	Scan for threats (All)	Scan outside (CP)
0	2_2_22	Scan for threats (All)	Delay
0	2_2_23	Scan for threats (All)	Delay1
0	2_2_24	Scan for threats (All)	Dispense counter- measures (P)
0	2_2_5	Scan for threats (All)	Call threat (P)
0	2_2_6	Scan for threats (All)	Scan outside (LM)
0	2_2_7	Scan for threats (All)	Dispense counter- measures (CP)
0	2_2_8	Scan for threats (All)	Maneuver airplane (P)
0	2_2_9	Scan for threats (All)	Call threat (CP)
0	2_2_999	Scan for threats (All)	END
0	2_3_0	Monitor Aircraft Performance (P)	START
0	2_3_1_0	Navigate the Airplane (P)	START Navigating
0.1	2_3_1_2	Navigate the Airplane (P)	Read stick diagram
0.15/.2	2_3_1_3	Navigate the Airplane (P)	Monitor SCNS Distance to Go
0.15/.2	2_3_1_4	Navigate the Airplane (P)	Monitor SCNS Xtrck
0.15/.2	2_3_1_5	Navigate the Airplane (P)	Monitor Heading
0.15/.2	2_3_1_6	Navigate the Airplane (P)	Monitor Ground Speed
0	2_3_1_7	Navigate the Airplane (P)	Ensure terrain clearance
0	2_3_1_8	Navigate the Airplane (P)	Calculate time status
0	2_3_1_9	Navigate the Airplane (P)	Routing
0	2_3_1_999	Navigate the Airplane (P)	END
0.15/.2	2_3_10	Monitor Aircraft Performance (P)	Monitor Vertical velocity
0	2_3_11	Monitor Aircraft Performance (P)	Routing
0	2_3_13	Monitor Aircraft Performance (P)	Form Routing
0	2_3_14	Monitor Aircraft Performance (P)	Autopilot?
0	2_3_15	Monitor Aircraft Performance (P)	Delay
0	2_3_2_0	Formation Position (P)	START Formation Flying
0	2_3_2_2	Formation Position (P)	Calculate Pursuit Curve
0	2_3_2_3	Formation Position (P)	Calculate Closure velocity
0.15/.2	2_3_2_4	Formation Position (P)	Monitor SKE in-track distance
0.15/.2	2_3_2_5	Formation Position (P)	Monitor Elevation WRT Lead
0.15/.2	2_3_2_6	Formation Position (P)	Monitor SKE Xtrack
0	2_3_2_7	Formation Position (P)	Routing
0	2_3_2_999	Formation Position (P)	END
0	2_3_4	Monitor Aircraft Performance (P)	Nothing
0	2_3_5	Monitor Aircraft Performance (P)	Calculate Pilot correction
0.15/.2	2_3_6	Monitor Aircraft Performance (P)	Monitor pitch
0.15/.2	2_3_7	Monitor Aircraft Performance (P)	Monitor airspeed
0.15/.2	2_3_8	Monitor Aircraft Performance (P)	Monitor bank angle
0.15/.2	2_3_9	Monitor Aircraft Performance (P)	Monitor altitude

0	2_3_999	Monitor Aircraft Performance (P)	END
0	2_4_0	Pilot Monitoring Duties (CP)	START
0	2_4_1_0	Navigate the Airplane (CP)	START Navigating
0.1	2_4_1_2	Navigate the Airplane (CP)	Read chart
0.15/.2	2_4_1_3	Navigate the Airplane (CP)	Monitor Distance to Go
0.15/.2	2_4_1_4	Navigate the Airplane (CP)	Monitor SCNS Xtrck
0.15/.2	2_4_1_5	Navigate the Airplane (CP)	Monitor Heading
0.15/.2	2_4_1_6	Navigate the Airplane (CP)	Monitor Ground Speed
0	2_4_1_7	Navigate the Airplane (CP)	Ensure terrain clearance
0	2_4_1_8	Navigate the Airplane (CP)	Calculate time status
0	2_4_1_9	Navigate the Airplane (CP)	Routing
0	2_4_1_999	Navigate the Airplane (CP)	END
0.15/.2	2_4_10	Pilot Monitoring Duties (CP)	Monitor pitch
0	2_4_12	Pilot Monitoring Duties (CP)	Form Routing
0	2_4_13	Pilot Monitoring Duties (CP)	Autopilot?
0	2_4_14	Pilot Monitoring Duties (CP)	Delay
0	2_4_2_0	Formation Position (CP)	START Formation Flying
0	2_4_2_2	Formation Position (CP)	Calculate Pursuit Curve
0	2_4_2_3	Formation Position (CP)	Calculate Closure velocity
0.15/.2	2_4_2_4	Formation Position (CP)	Monitor SKE in-track distance
0.15/.2	2_4_2_5	Formation Position (CP)	Monitor Elevation WRT Lead
0.15/.2	2_4_2_6	Formation Position (CP)	Monitor SKE Xtrack
0	2_4_2_999	Formation Position (CP)	END
0.15/.2	2_4_4	Pilot Monitoring Duties (CP)	Monitor airspeed
0.15/.2	2_4_5	Pilot Monitoring Duties (CP)	Monitor bank angle
0.15/.2	2_4_6	Pilot Monitoring Duties (CP)	Monitor altitude
0.15/.2	2_4_7	Pilot Monitoring Duties (CP)	Monitor Vertical velocity
0	2_4_8	Pilot Monitoring Duties (CP)	Provide Feedback to Pilot
0.25	2_4_9	Pilot Monitoring Duties (CP)	Evaluate Aircraft Performance
0	2_4_999	Pilot Monitoring Duties (CP)	END
0	2_6_0	Monitor systems (CP)	START
0	2_6_10	Monitor systems (CP)	Monitor system health
0	2_6_12	Monitor systems (CP)	Delay
0.05	2_6_3	Monitor systems (CP)	Listen (P)
0	2_6_6	Monitor systems (CP)	Decide/Observe
0	2_6_7	Monitor systems (CP)	Troubleshoot
0	2_6_999	Monitor systems (CP)	Report problem
0	2_7_0	Listen to Radios (All)	START
0.05	2_7_2	Listen to Radios (All)	Listen to Radios (P)
0.05	2_7_3	Listen to Radios (All)	Listen to Radios (CP)
0	2_7_999	Listen to Radios (All)	END
0.05	2_9	Basic Aircraft Control (C-130J)	Listen (P)
0	2_999	Basic Aircraft Control (C-130J)	END
0	3_0	Situation Awareness (C-130J)	START
0	3_1_0	Pilot SA	START
0	3_1_2	Pilot SA	Low SA
0	3_1_3	Pilot SA	High SA
0	3_1_4	Pilot SA	Medium SA

0	3_1_5	Pilot SA	Delay
0	3_1_999	Pilot SA	END
0	3_2_0	Copilot SA	START
0	3_2_2	Copilot SA	Low SA
0	3_2_3	Copilot SA	High SA
0	3_2_4	Copilot SA	Medium SA
0	3_2_5	Copilot SA	Delay
0	3_2_999	Copilot SA	END
0	3_999	Situation Awareness (C-130J)	END
0	4_0	Situation Awareness (C-130H)	START
0	4_1_0	Pilot SA	START
0	4_1_2	Pilot SA	Low SA
0	4_1_3	Pilot SA	High SA
0	4_1_4	Pilot SA	Medium SA
0	4_1_5	Pilot SA	Delay
0	4_1_999	Pilot SA	END
0	4_2_0	Copilot SA	START
0	4_2_2	Copilot SA	Low SA
0	4_2_3	Copilot SA	High SA
0	4_2_4	Copilot SA	Medium SA
0	4_2_5	Copilot SA	Delay
0	4_2_999	Copilot SA	END
0	4_3_0	Navigator SA	START
0	4_3_2	Navigator SA	Low SA
0	4_3_3	Navigator SA	High SA
0	4_3_4	Navigator SA	Medium SA
0	4_3_5	Navigator SA	Delay
0	4_3_999	Navigator SA	END
0	4_4_0	Engineer SA	START
0	4_4_2	Engineer SA	Low SA
0	4_4_3	Engineer SA	High SA
0	4_4_4	Engineer SA	Medium SA
0	4_4_5	Engineer SA	Delay
0	4_4_999	Engineer SA	END
0	4_999	Situation Awareness (C-130H)	END
0	999	(Root)	Model END

Table 29: Task Listing and Tactical SA Values for SKE Formation Airdrop (C-130H)

Tac SA Value	Task ID	Function	Task
0	0	(Root)	Model START
0	19_0	Preslowdown Checklist	START
0	19_1	Preslowdown Checklist	Crew, 20 min advisory (N)
0	19_10	Preslowdown Checklist	Load is off headset (LM)
0	19_11	Preslowdown Checklist	Brief Airdrop card (CP)
0	19_12	Preslowdown Checklist	Reviewed, Pilot (P)
0	19_13	Preslowdown Checklist	Copilot (CP)
0	19_14	Preslowdown Checklist	Nav (N)
0	19_15	Preslowdown Checklist	set radar altimeter (P)
0	19_16	Preslowdown Checklist	Set Radar altimeter (N)
0	19_17	Preslowdown Checklist	Radar altimeter (E)
0.05	19_18	Preslowdown Checklist	Set xxx, Pilot
0	19_19	Preslowdown Checklist	Set xxx, Nav (N)
0	19_2	Preslowdown Checklist	Post drop information on card (N)
0	19_20_0	Depressurize (E)	Is altitude appropriate?
0	19_20_2	Depressurize (E)	Set cabin rate knob
0	19_20_3	Depressurize (E)	Set pressure controller
0	19_20_4	Depressurize (E)	set air cond master switch
0	19_20_999	Depressurize (E)	Cabin diff press =0
0	19_21	Preslowdown Checklist	Red Light (E)
0	19_22	Preslowdown Checklist	Turn on Troop Caution (CP)
0	19_23	Preslowdown Checklist	On (CP)
0	19_24	Preslowdown Checklist	(Jumpers stand)
0	19_25	Preslowdown Checklist	Drift and Altimeter setting (E)
0	19_26	Preslowdown Checklist	Relayed xx L/R (N)
0	19_27	Preslowdown Checklist	Compute SKE run-in XTRK (CP)
0	19_28	Preslowdown Checklist	Computer Airdrop Information (E)
0.05	19_29	Preslowdown Checklist	Pass Airdrop drift FCI
0	19_3	Preslowdown Checklist	Preslowdown Checklist (N)
0.05	19_30	Preslowdown Checklist	Relay Altimeter FCI
0.05	19_31	Preslowdown Checklist	Relay drift (N)
0.05	19_32	Preslowdown Checklist	Relay altimeter (N)
0	19_33_0	Check computer info (N)	START
0	19_33_1	Check computer info (N)	Enter/verify TOT
0	19_33_2	Check computer info (N)	Program ballistic winds
0	19_33_3	Check computer info (N)	Verify Ballistic data
0	19_33_4	Check computer info (N)	Confirm drop reference
0	19_33_5	Check computer info (N)	Set Altitude gate
0	19_33_6	Check computer info (N)	Program wind factor
0	19_33_999	Check computer info (N)	Checked (N)
0	19_34	Preslowdown Checklist	SKE secondary control panel (E)
0	19_35	Preslowdown Checklist	Reset SKE XTRK (CP)
0.05	19_36	Preslowdown Checklist	Set xxx L/R (CP)

0	19_37	Preslowdown Checklist	Adjust lateral position
0	19_38	Preslowdown Checklist	AD/TJ switch (E)
0.1	19_39	Preslowdown Checklist	Verify switch (CP)
0.05	19_4	Preslowdown Checklist	Crew, 10 min advisory (N)
0.05	19_40	Preslowdown Checklist	AD/TJ Manual (CP)
0	19_41	Preslowdown Checklist	Preslowdown checks (E)
0.05	19_42	Preslowdown Checklist	Load is back up (LM)
0.05	19_43	Preslowdown Checklist	Complete, Load (LM)
0	19_44	Preslowdown Checklist	Acknowledged, Load (LM)1
0.05	19_46	Preslowdown Checklist	Listen to brief (P)
0.05	19_47	Preslowdown Checklist	Listen to brief (N)
0.05	19_48	Preslowdown Checklist	Listen to brief (E)
0	19_5	Preslowdown Checklist	Personnel Checklist (P)
0	19_6	Preslowdown Checklist	Open checklist (E)
0	19_7	Preslowdown Checklist	Post stall speeds on drop card (E)
0	19_8	Preslowdown Checklist	Acknowledged, Load (LM)
0	19_9	Preslowdown Checklist	Slowdown, drop zone , and escape (E)
0.05	19_999	Preslowdown Checklist	Complete, Engineer (E)
0	20_0	Formation descent	Approaching top of descent
0.05	20_1	Formation descent	Pass new altitude (FCI)
0.05	20_10	Formation descent	Next altitude xxxx (N)
0.05	20_11	Formation descent	Relay 30 sec FCI (N)
0.05	20_12	Formation descent	5 sec (N)
0.1	20_13	Formation descent	Verify clear of terrain
0.05	20_14	Formation descent	Clear of terrain (N)
0.05	20_15	Formation descent	Relay 5 sec FCI (P)
0.05	20_16	Formation descent	Passed
0.05	20_17	Formation descent	Relay "E" FCI (P)
0.05	20_18	Formation descent	Passed (P)1
0.05	20_2	Formation descent	Pass 30 sec FCI
0	20_20	Formation descent	Descend 1000 ft/min
0	20_21	Formation descent	Level off (P)
0.05	20_24	Formation descent	1000 above (CP)
0.05	20_3	Formation descent	Pass 5 sec FCI
0.05	20_4	Formation descent	Pass Execute FCI
0	20_5	Formation descent	Level out
0.05	20_6	Formation descent	Lead is level @ xxxx
0.05	20_7	Formation descent	2 is level
0.05	20_8	Formation descent	Relay Altitude (FCI)
0.05	20_9	Formation descent	Lead's 30 sec downprep (N)
0	20_999	Formation descent	3 is level
0	21_0	Formation turn at IP	Approaching turn point
0.05	21_1	Formation turn at IP	Pass TAS (FCI)
0.05	21_10	Formation turn at IP	Pass 5 sec (FCI)
0.05	21_11	Formation turn at IP	Pass execute (FCI)
0.05	21_12	Formation turn at IP	30 sec, passed (N)
0.05	21_13	Formation turn at IP	Relay FCI (N)
0	21_14	Formation turn at IP	Compute time delay (N)

0.05	21_15	Formation turn at IP	State time delay (N)
0.15	21_16	Formation turn at IP	Read in-track dist (CP)
0.05	21_17	Formation turn at IP	State in track dist (CP)
0	21_19	Formation turn at IP	Compute PPI offset (CP)
0.05	21_2	Formation turn at IP	Pass present hdg (FCI)
0.15	21_20	Formation turn at IP	Reset PPI ref line (CP)
0.05	21_21	Formation turn at IP	5 sec (N)
0.05	21_22	Formation turn at IP	Relay FCI (P)
0.05	21_23	Formation turn at IP	Passed (P)
0.05	21_24	Formation turn at IP	begin turn (N)
0.05	21_25	Formation turn at IP	Relay "E" FCI (P)
0.05	21_26	Formation turn at IP	Passed (P)1
0	21_27	Formation turn at IP	begin turn (P)
0.1	21_28	Formation turn at IP	Begin turn (Lead)
0.1	21_29	Formation turn at IP	Roll out (Lead)
0.05	21_3	Formation turn at IP	Pass next hdg (FCI)
0.15	21_30	Formation turn at IP	Observe Lead's turn (CP)
0.05	21_31	Formation turn at IP	Lead is in the turn (CP)
0.05	21_32	Formation turn at IP	Provide trend info (CP)
0.05	21_4	Formation turn at IP	Lead is loading computer turn (N)
0.05	21_5	Formation turn at IP	Relay TAS (N)
0.05	21_6	Formation turn at IP	Relay present hdg (N)
0.05	21_7	Formation turn at IP	Relay next hdg (N)
0.05	21_8	Formation turn at IP	Box is loaded (N)
0.05	21_9	Formation turn at IP	Pass 30 sec (FCI)
0	21_999	Formation turn at IP	Roll out (P)
0	22_0	Slowdown checklist	Approach SD point
0.05	22_1	Slowdown checklist	Pass 30 sec SD (FCI)
0.05	22_10	Slowdown checklist	Passed (P)
0.05	22_11	Slowdown checklist	Slowdown, slowdown, now (N)
0.05	22_12	Slowdown checklist	Relay "E" FCI (P)
0.05	22_13	Slowdown checklist	Flaps 50, on speed (P)
0	22_14	Slowdown checklist	Retard throttles (P)
0.05	22_15_0	Move flaps 50% (CP)	Flaps tracking 50%, on speed (CP)
0	22_15_10	Move flaps 50% (CP)	Move flaps to 50% (CP)
0.15	22_15_11	Move flaps 50% (CP)	Observe rudder hyrdaulic pressure increase (CP)
0.15	22_15_12	Move flaps 50% (CP)	Observe rudder hyrdaulic pressure increase (E)
0.15	22_15_3	Move flaps 50% (CP)	Observe <210 KIAS (CP)
0	22_15_4	Move flaps 50% (CP)	Move flaps to 20% (CP)
0.15	22_15_5	Move flaps 50% (CP)	Observe <200 KIAS (CP)
0	22_15_6	Move flaps 50% (CP)	Move flaps to 30% (CP)
0.15	22_15_7	Move flaps 50% (CP)	Observe <190 KIAS (CP)
0	22_15_8	Move flaps 50% (CP)	Move flaps to 40% (CP)
0.15	22_15_9	Move flaps 50% (CP)	Observe <180 KIAS (CP)
0	22_15_999	Move flaps 50% (CP)	END

0	22_16	Slowdown checklist	Silence warning horn (CP)
0	22_17	Slowdown checklist	Slow to 140 KIAS (P)
0.15	22_19	Slowdown checklist	Observe <150 KIAS (E)
0.05	22_2	Slowdown checklist	30 sec to slowdown (N)
0	22_20	Slowdown checklist	Air deflector doors (E)
0	22_21	Slowdown checklist	throw switch (CP)
0.05	22_22	Slowdown checklist	observe light (CP)
0.05	22_23	Slowdown checklist	Indicate open (CP)
0	22_24	Slowdown checklist	Open paratroop door (LM)
0	22_25	Slowdown checklist	Drift and wind information (E)
0	22_26	Slowdown checklist	Add power to maintain 140 KIAS (P)
0	22_27	Slowdown checklist	Contact Drop zone
0.05	22_28	Slowdown checklist	Recieve DZ winds
0.05	22_29	Slowdown checklist	Pass updated drift data (FCI)
0.05	22_3	Slowdown checklist	Pass 5 sec SD (FCI)
0	22_30	Slowdown checklist	Lead is 140 KIAS
0.15	22_31	Slowdown checklist	Arrive @ earliest descent point
0	22_32	Slowdown checklist	IFF/TCAS (E)
0	22_33	Slowdown checklist	Flaps (E)
0.05	22_34	Slowdown checklist	50% (CP)
0.1	22_35	Slowdown checklist	verify STBY (CP)
0.05	22_36	Slowdown checklist	Set, standby (CP)
0.05	22_37	Slowdown checklist	Pass 5 sec (FCI)
0.05	22_38	Slowdown checklist	Pass "E" (FCI)
0	22_39_0	Compute independent ballistic info (N)	Update CARP (N)
0.1	22_39_1	Compute independent ballistic info (N)	Verbalize new CARP (N)
0.05	22_39_2	Compute independent ballistic info (N)	Repeat new CARP (P)
0	22_39_3	Compute independent ballistic info (N)	Compute new GS (N)
0	22_39_4	Compute independent ballistic info (N)	Program new CARP in SCNS (N)
0	22_39_5	Compute independent ballistic info (N)	Compute in-track timing (N)
0.05	22_39_6	Compute independent ballistic info (N)	Relay drift FCI (N)
0	22_39_999	Compute independent ballistic info (N)	END
0.05	22_4	Slowdown checklist	Relay 30 sec FCI (N)
0.05	22_40	Slowdown checklist	Relayed (N)
0.05	22_41	Slowdown checklist	Complete, Load (LM)
0	22_42	Slowdown checklist	Lead descends to drop altitude
0	22_43	Slowdown checklist	Lead slows to 130 KIAS
0.05	22_44	Slowdown checklist	Lead's down prep (N)
0.05	22_47	Slowdown checklist	Relay 5 sec FCI
0.05	22_48	Slowdown checklist	relay FCI (P)
0.05	22_49	Slowdown checklist	descend now (N)
0.05	22_5	Slowdown checklist	Passed (N)
0.05	22_51	Slowdown checklist	confirm clear of terrain (N)
0	22_52	Slowdown checklist	Retard throttles (P)1
0	22_53	Slowdown checklist	Descend to drop alt +50ft (P)

0	22_54	Slowdown checklist	Slow to 130 KIAS
0	22_55	Slowdown checklist	Adjust formation position (P)
0	22_56	Slowdown checklist	stop descent /level (P)
0	22_57	Slowdown checklist	Slowdown Checks (E)
0.05	22_58	Slowdown checklist	Complete, Eng (E)
0	22_59	Slowdown checklist	Pull hot mike knob (P)
0.05	22_6	Slowdown checklist	Pass execute (FCI)
0	22_60	Slowdown checklist	Pull hot mike knob (CP)
0.05	22_61	Slowdown checklist	Pilot is hot mike (P)
0.05	22_62	Slowdown checklist	Copilot is hot mike (CP)
0.1	22_63	Slowdown checklist	Clear to drop (DZ)
0.05	22_64	Slowdown checklist	Acknowledge (P)
0.05	22_65	Slowdown checklist	Acknowledge (CP)
0.05	22_66	Slowdown checklist	Acknowledge (N)
0.05	22_67	Slowdown checklist	Acknowledge (E)
0.05	22_7	Slowdown checklist	[callsign] slowdown, slow down, now
0.05	22_8	Slowdown checklist	5 sec to slowdown (N)
0.05	22_9	Slowdown checklist	Relay 5 sec FCI (P)
0	22_999	Slowdown checklist	END
0	24_0	Release Point Checklist	START
0.05	24_10	Release Point Checklist	No drop (P)
0.05	24_11	Release Point Checklist	No drop (CP)
0.05	24_12	Release Point Checklist	No drop (N)
0.05	24_13	Release Point Checklist	No drop (E)
0.2	24_14	Release Point Checklist	Aircraft safe to drop? (P)
0.2	24_15	Release Point Checklist	Aircraft safe to drop? (CP)
0.2	24_16	Release Point Checklist	Aircraft safe to drop? (E)
0.1	24_17	Release Point Checklist	Evaluate SCNS time (N)
0.05	24_18	Release Point Checklist	Timing is good (N)
0.1	24_19	Release Point Checklist	Evaluate SCNS xtrk (P)
0.05	24_2	Release Point Checklist	1 min advisory (N)
0.05	24_20	Release Point Checklist	SCNS is good (P)
0.2	24_21	Release Point Checklist	Aircraft safe to drop? (N)
0.1	24_22	Release Point Checklist	Evaluate formation position (CP)
0.05	24_23	Release Point Checklist	TWS is good (CP)
0.05	24_24	Release Point Checklist	5 sec (FCI)
0.15	24_25	Release Point Checklist	Observe SCNS time (N)
0.05	24_26	Release Point Checklist	5 sec (N)
0.05	24_27	Release Point Checklist	Relay 5 sec FCI (P)
0.05	24_28	Release Point Checklist	Passed (P)1
0.05	24_29	Release Point Checklist	Execute (FCI)
0.05	24_3	Release Point Checklist	Relay 1 min FCI (P)
0.1	24_30	Release Point Checklist	Observe GL time (N)
0.05	24_31	Release Point Checklist	Green Light! (N)
0.05	24_32	Release Point Checklist	Relay "E" FCI (P)
0	24_33	Release Point Checklist	turn on light (CP)
0.05	24_34	Release Point Checklist	On! (CP)
0	24_35_0	Fly to CARP (P)	START

0.15	24_35_1	Fly to CARP (P)	maintain SKE xtrk position (P)	
0.15	24_35_2	Fly to CARP (P)	minimize SCNS xtrk (P)	
0.1	24_35_3	Fly to CARP (P)	minimize TKE (P)	
0.15	24_35_4	Fly to CARP (P)	maintain element drop altitude (P)	
0.15	24_35_5	Fly to CARP (P)	maintain drop airspeed (P)	
0.15	24_35_6	Fly to CARP (P)	maintain SKE in-track spacing (P)	
0	24_35_999	Fly to CARP (P)	END	
0.05	24_36	Release Point Checklist	Acknowledged, Copilot (CP)1	
0.05	24_37	Release Point Checklist	Acknowledged, Load (LM)1	
0	24_38	Release Point Checklist	Formation cleared to drop?	
0	24_39	Release Point Checklist	Formation safe to drop?	
0.05	24_4	Release Point Checklist	Passed (P)	
0.05	24_40	Release Point Checklist	Pass no drop (FCI)	
0.05	24_41	Release Point Checklist	Relay FCI (N))	
0.05	24_42	Release Point Checklist	xxxx, no drop, ack	
0.05	24_43	Release Point Checklist		2
0	24_44	Release Point Checklist	3 (P)	
0	24_45	Release Point Checklist	Jumpers exit	
0.05	24_46_0	Drop Malfunction	Pilot, malfunction (LM)	
0.05	24_46_1	Drop Malfunction	Brief description (LM)	
0	24_46_2	Drop Malfunction	Perform emergency actions (LM)	
0	24_46_3	Drop Malfunction	Perform emergency actions (P)	
0	24_46_4	Drop Malfunction	Perform emergency actions (CP)	
0	24_46_5	Drop Malfunction	Perform emergency actions (N)	
0	24_46_6	Drop Malfunction	Perform emergency actions (FE)	
0	24_46_999	Drop Malfunction	END	
0	24_47	Release Point Checklist	Time for usable DZ (N)	
0.05	24_48	Release Point Checklist	load clear (LM)	
0.05	24_5	Release Point Checklist	Acknowledged, Load (LM)	
0.05	24_50	Release Point Checklist	Red light (N)	
0	24_51	Release Point Checklist	turn off light (CP)	
0.05	24_52	Release Point Checklist	on (CP)	
0	24_53	Release Point Checklist	Time for 60 sec	
0	24_54	Release Point Checklist	Nothing	
0.05	24_7	Release Point Checklist	1 min warn (FCI)	
0	24_8	Release Point Checklist	Are jumpers safe?	
0.05	24_9	Release Point Checklist	No drop (LM)	
0	24_999	Release Point Checklist	END	
0	25_0	Completion of Drop checklist	START	
0	25_1	Completion of Drop checklist	Paratroop doors (E)	
0	25_10	Completion of Drop checklist	Adjust formation postn (P)	
0.05	25_11	Completion of Drop checklist	Accelerate, Accelerate now (N)	
0	25_12	Completion of Drop checklist	set AC master switch (E)	
0	25_13	Completion of Drop checklist	Set cabin px controller (E)	
0	25_14	Completion of Drop checklist	set rate knob (E)	
0	25_15	Completion of Drop checklist	add throttles (P)	
0.05	25_16	Completion of Drop checklist	Pass "E" FCI (P)	
0.05	25_17	Completion of Drop checklist	Flaps up (P)	

0.05	25_18	Completion of Drop checklist	Flaps tracking up (CP)
0	25_19	Completion of Drop checklist	Move flap lever (CP)
0	25_2	Completion of Drop checklist	Close doors (LM)
0	25_20	Completion of Drop checklist	Flaps (E)
0.05	25_21	Completion of Drop checklist	up (CP)
0.15	25_22	Completion of Drop checklist	Observe flaps 0% (E)
0	25_23	Completion of Drop checklist	IFF/TCAS (E)
0.15	25_24	Completion of Drop checklist	verify stdby (CP)
0.05	25_25	Completion of Drop checklist	Set, STBY (CP)
0	25_26	Completion of Drop checklist	Radar altimeter (E)
0	25_27	Completion of Drop checklist	redial radar alt (P)
0	25_28	Completion of Drop checklist	redial radar alt (N)
0.05	25_29	Completion of Drop checklist	Set, xxx, pilot (P)
0.05	25_3	Completion of Drop checklist	Closed and locked (LM)
0.05	25_30	Completion of Drop checklist	Set xxx Nav (N)
0	25_31	Completion of Drop checklist	AD/TJ swtich (E)
0.1	25_32	Completion of Drop checklist	verify MAN (CP)
0.05	25_33	Completion of Drop checklist	AD/TJ manual (CP)
0	25_34	Completion of Drop checklist	Red light (E)
0	25_35	Completion of Drop checklist	switch off (CP)
0.05	25_36	Completion of Drop checklist	off (CP)
0	25_37	Completion of Drop checklist	Drop checks (E)
0.05	25_38	Completion of Drop checklist	Complete, Load (LM)
0.05	25_39	Completion of Drop checklist	Complete, Engineer (E)
0	25_4	Completion of Drop checklist	close AD switch (CP)
0.05	25_40	Completion of Drop checklist	Pass 5 sec FCI
0.05	25_41	Completion of Drop checklist	Lead's 5 sec turn prep (N)
0	25_42	Completion of Drop checklist	Calculate time delay (N)
0.05	25_44	Completion of Drop checklist	Pass execute FCI
0.05	25_45	Completion of Drop checklist	state in- track position (CP)
0.15	25_46	Completion of Drop checklist	set PPI line (CP)
0.05	25_47	Completion of Drop checklist	Relay 5 sec FCI (P)
0.05	25_48	Completion of Drop checklist	Relay "E" FCI (P)
0.05	25_49	Completion of Drop checklist	L/R turn xxx (N)
0.05	25_5	Completion of Drop checklist	indicate closed (CP)
0.15	25_50	Completion of Drop checklist	monitor lead's position (CP)
0	25_51	Completion of Drop checklist	advance throttles (P)
0	25_52	Completion of Drop checklist	Accelerate 140 KIAS (P)
0	25_53	Completion of Drop checklist	Climb 1000 ft/min (P)
0	25_54	Completion of Drop checklist	Level @ new alt (P)
0	25_55	Completion of Drop checklist	Turn to escape heading (P)
0.05	25_56	Completion of Drop checklist	provide trend info to Pilot (CP)
0	25_57	Completion of Drop checklist	Roll out on course (P)
0.05	25_58	Completion of Drop checklist	Lead is lvl xxxx
0.05	25_59	Completion of Drop checklist	2 is level
0	25_6	Completion of Drop checklist	air deflector doors (E)
0	25_60	Completion of Drop checklist	3 is level (P)
0.15	25_61	Completion of Drop checklist	Pass new IAS (FCI)

0.05	25_62	Completion of Drop checklist	Relay IAS FCI (N)
0.05	25_63	Completion of Drop checklist	New speed xxx (N)
0.05	25_64	Completion of Drop checklist	Pass 30 sec (FCI)1
0.05	25_65	Completion of Drop checklist	Relay 30 sec FCI (N)
0.05	25_66	Completion of Drop checklist	30 sec prep, Passed (N)
0.05	25_67	Completion of Drop checklist	Pass 5 sec (FCI)
0.05	25_68	Completion of Drop checklist	5 sec (N)
0.05	25_69	Completion of Drop checklist	Relay 5 sec FCI (P)
0	25_7	Completion of Drop checklist	SKE 2nd cntrl panel (E)
0.05	25_70	Completion of Drop checklist	passed (P)
0.05	25_71	Completion of Drop checklist	Pass "E" (FCI)1
0	25_72	Completion of Drop checklist	accelerate
0	25_73	Completion of Drop checklist	adjust throttles (P)
0	25_74	Completion of Drop checklist	Adjust formation postn (P)1
0	25_8	Completion of Drop checklist	reset SKE panel (CP) Set, (state setting) (CP) 25_999 Completion of Drop checklist END 26_0 AWADS updates (N) START 26_1 AWADS updates (N) AWADS Update 1 26_2 AWADS updates (N) AWADS Update 2 26_3 AWADS updates (N) AWADS Update 3 26_999 AWADS updates (N) END 44_0 Freq change START 44_1 Freq change Direct freq change1 44_2 Freq change Acknowledge (P)2 44_3 Freq change Change radios (CP)1 44_4 Freq change Check in1 44_5 Freq change Acknowledge (P)3 44_999 Freq change END 45_0 Freq change1 START 45_10 Freq change1 Copy drop scores (N) 45_3 Freq change1 Obtain drop scores 45_4 Freq change1 Direct freq change 45_5 Freq change1 Acknowledge (P) 45_6 Freq change1 Change radios (CP) 45_7 Freq change1 Check in 45_8 Freq change1 Acknowledge (P)1 45_9 Freq change1 Copy drop scores (CP)
variable	25_9	Completion of Drop checklist	45_999 Freq change1 END

	999	(Root)	Model END

Table 30: Task Listing and Tactical SA Values for SKE Formation Airdrop scenario (C-130J)

Tac SA Value	Task ID	Function	Task
0	0	(Root)	Model START
0	19_0	Drop Preparation Checklist	START
0	19_1	Drop Preparation Checklist	Crew, 20 min advisory (CP)
0	19_10	Drop Preparation Checklist	Load is off headset (LM)
0	19_11	Drop Preparation Checklist	Brief Airdrop card (CP)
0	19_13	Drop Preparation Checklist	Complete (CP)
0	19_15	Drop Preparation Checklist	set radar altimeter (P)
0	19_16	Drop Preparation Checklist	Set Radar altimeter (CP)
0	19_17	Drop Preparation Checklist	Altimeters (CP)
0.05	19_18	Drop Preparation Checklist	Set xxx, Pilot
0	19_19	Drop Preparation Checklist	Set xxx, Copilot (N)
0	19_20_0	Depressurize (CP)	Is altitude appropriate?
0	19_20_4	Depressurize (CP)	set air cond master switch
0	19_20_999	Depressurize (CP)	END
0	19_22	Drop Preparation Checklist	Turn on Troop Caution (CP)
0	19_23	Drop Preparation Checklist	Red Light On (CP)
0	19_24	Drop Preparation Checklist	(Jumpers stand)
0	19_26	Drop Preparation Checklist	Relayed xx L/R (CP)
0	19_28	Drop Preparation Checklist	Cabin Depressurized (CP)
0.05	19_29	Drop Preparation Checklist	Pass Airdrop drift FCI
0	19_3	Drop Preparation Checklist	Drop Preperation Personnel Checklist (P)
0.05	19_30	Drop Preparation Checklist	Relay Altimeter FCI
0	19_31	Drop Preparation Checklist	Input drift (CP)

0.05	19_32	Drop Preparation Checklist	Relay altimeter (CP)
0	19_33_0	Check CNI-MU CARP data (CP)	START
0	19_33_1	Check CNI-MU CARP data (CP)	Verify CARP Page 1
0	19_33_2	Check CNI-MU CARP data (CP)	Verify CARP Page 2
0	19_33_3	Check CNI-MU CARP data (CP)	Verify CARP Page 3
0	19_33_4	Check CNI-MU CARP data (CP)	Verify CARP Page 4
0	19_33_5	Check CNI-MU CARP data (CP)	Verify CARP Page 5
0	19_33_999	Check CNI-MU CARP data (CP)	END
0.05	19_39	Drop Preparation Checklist	Computer drop switch-Manual (CP)
0.05	19_4	Drop Preparation Checklist	Crew, 10 min advisory (CP)
0	19_41	Drop Preparation Checklist	Drop preparation checks (CP)
0.05	19_42	Drop Preparation Checklist	Load is back up (LM)
0.05	19_43	Drop Preparation Checklist	Complete, Load (LM)
0.05	19_44	Drop Preparation Checklist	Acknowledged, Load (LM)1
0.05	19_46	Drop Preparation Checklist	Listen to brief (P)
0.05	19_47	Drop Preparation Checklist	Relay drop altitude (CP)
0	19_6	Drop Preparation Checklist	Open checklist (CP)
0.05	19_8	Drop Preparation Checklist	Acknowledged, Load (LM)
0.05	19_999	Drop Preparation Checklist	Complete Copilot (CP)
0	20_0	Formation descent	Approaching top of descent
0.05	20_1	Formation descent	Pass new altitude (FCI)
0.05	20_10	Formation descent	Next altitude xxxx (P)
0.05	20_11	Formation descent	Relay 30 sec FCI (J)
0.1	20_13	Formation descent	Verify clear of terrain
0.05	20_14	Formation descent	Clear of terrain (CP)
0	20_15	Formation descent	Relay 5 sec FCI (J)
0	20_16	Formation descent	Passed
0	20_17	Formation descent	Relay "E" FCI (J)
0	20_18	Formation descent	Autopilot pitch wheel down (P)
0.05	20_2	Formation descent	Pass 30 sec FCI
0	20_20	Formation descent	Descend
0	20_21	Formation descent	Level off (J)
0.05	20_24	Formation descent	1000 above (CP)
0	20_3	Formation descent	Pass 5 sec FCI
0	20_4	Formation descent	Pass Execute FCI
0	20_5	Formation descent	Level out
0.05	20_6	Formation descent	Lead is level @ xxxx
0.05	20_7	Formation descent	2 is level
0	20_8	Formation descent	Dial new alt in REF MODE (P)
0.05	20_9	Formation descent	Lead's 30 sec downprep (P)
0	20_999	Formation descent	3 is level
0	21_0	Formation turn at IP	Approaching turn point
0	21_1	Formation turn at IP	Pass TAS (FCI)
0	21_10	Formation turn at IP	Pass 5 sec (FCI)
0	21_11	Formation turn at IP	Pass execute (FCI)
0	21_12	Formation turn at IP	30 sec, passed (J)
0	21_13	Formation turn at IP	Relay FCI (J)1
0	21_14	Formation turn at IP	Compute time delay (J)

0	21_15	Formation turn at IP	State time delay (J)
0	21_16	Formation turn at IP	Read in-track dist (J)
0	21_17	Formation turn at IP	State in track dist (J)
0	21_2	Formation turn at IP	Pass present hdg (FCI)
0	21_22	Formation turn at IP	Relay FCI (J)
0	21_23	Formation turn at IP	Passed (J)
0	21_25	Formation turn at IP	Relay "E" FCI (J)
0	21_26	Formation turn at IP	Passed (J)1
0	21_27	Formation turn at IP	begin turn (J)
0.25	21_28	Formation turn at IP	Begin turn (Lead)
0.25	21_29	Formation turn at IP	Roll out (Lead)
0.05	21_3	Formation turn at IP	Pass next hdg (FCI)
0.25	21_30	Formation turn at IP	Observe Lead's turn (CP)
0.05	21_31	Formation turn at IP	Lead is in the turn (CP)
0.25	21_32	Formation turn at IP	Provide trend info (J)
0.25	21_33	Formation turn at IP	Observe Lead's turn (P)
0	21_4	Formation turn at IP	Lead is loading computer turn (J)
0	21_5	Formation turn at IP	Relay TAS (J)
0	21_6	Formation turn at IP	Relay present hdg (J)
0	21_7	Formation turn at IP	Lead's next hdg (CP)
0	21_8	Formation turn at IP	Box is loaded (J)
0	21_9	Formation turn at IP	Pass 30 sec (FCI)
0.25	21_999	Formation turn at IP	Roll out (J)
0	22_0	Run-In checklist	Run-in checklist (P)
0.05	22_1	Run-In checklist	Pass 30 sec SD (FCI)
0	22_10	Run-In checklist	Passed (J)1
0.05	22_11	Run-In checklist	Slowdown, slowdown, now (P)
0.05	22_12	Run-In checklist	Relay "E" FCI (J)
0	22_14	Run-In checklist	Retard throttles (J)
0	22_15_0	Move flaps 50% (CP)	START
0	22_15_10	Move flaps 50% (CP)	Move flaps to 50% (CP)
0.15	22_15_11	Move flaps 50% (CP)	Observe rudder hyrdaulic pressure increase (CP)
0	22_15_12	Move flaps 50% (CP)	Flaps 50 (P)
0.15	22_15_13	Move flaps 50% (CP)	Observe <210 KIAS (P)
0.15	22_15_14	Move flaps 50% (CP)	Observe <200 KIAS (P)
0.15	22_15_15	Move flaps 50% (CP)	Observe <190 KIAS (P)
0.15	22_15_16	Move flaps 50% (CP)	Observe <180 KIAS (P)
0.15	22_15_3	Move flaps 50% (CP)	Observe <210 KIAS (CP)
0.15	22_15_5	Move flaps 50% (CP)	Observe <200 KIAS (CP)
0.15	22_15_7	Move flaps 50% (CP)	Observe <190 KIAS (CP)
0.15	22_15_9	Move flaps 50% (CP)	Observe <180 KIAS (CP)
0	22_15_999	Move flaps 50% (CP)	END
0	22_16	Run-In checklist	Silence warning horn (CP)
0	22_17	Run-In checklist	Slow to 140 KIAS (J)
0.15	22_19	Run-In checklist	Observe <150 KIAS "Clear for air deflectors" (P)

0.05	22_2	Run-In checklist	30 sec to slowdown (P)
0.05	22_21	Run-In checklist	Coming open throw switch (CP)
0.05	22_22	Run-In checklist	observe light (CP)
0.05	22_23	Run-In checklist	Air deflector doors Indicate open. Doors clear to open (CP)
0	22_24	Run-In checklist	Open paratroop door (LM)
0.05	22_25	Run-In checklist	Drift and wind information relayed (CP)
0	22_26	Run-In checklist	Add power to maintain 140 KIAS (J)
0	22_27	Run-In checklist	Contact Drop zone
0.05	22_28	Run-In checklist	Recieve DZ winds
0.05	22_29	Run-In checklist	Pass updated drift data (FCI)
0	22_3	Run-In checklist	Pass 5 sec SD (FCI)
0	22_30	Run-In checklist	Lead is 140 KIAS
0.15	22_31	Run-In checklist	Arrive @ earliest descent point
0.05	22_34	Run-In checklist	Flaps 50% (CP)
0	22_37	Run-In checklist	Pass 5 sec (FCI)
0	22_38	Run-In checklist	Pass "E" (FCI)
0	22_39_0	input new winds (CP)	Input new winds (CP)
0.05	22_39_1	input new winds (CP)	Verbalize new CARP (CP)
0.05	22_39_2	input new winds (CP)	Repeat new CARP (P)
0.05	22_39_3	input new winds (CP)	VERT GDNC Set, ___ (CP)
0.05	22_39_5	input new winds (CP)	X PATH OFS, Set 0 (CP)
0	22_39_999	input new winds (CP)	END
0	22_4	Run-In checklist	Relay 30 sec FCI (J)
0.05	22_41	Run-In checklist	Complete, Load (LM)
0	22_42	Run-In checklist	Lead descends to drop altitude
0	22_43	Run-In checklist	Lead slows to 130 KIAS
0	22_47	Run-In checklist	Relay 5 sec FCI
0	22_48	Run-In checklist	relay FCI (J)
0.05	22_49	Run-In checklist	descending (P)
0	22_5	Run-In checklist	Passed (J)
0.25	22_51	Run-In checklist	Confirm DZ entry point (P)
0	22_52	Run-In checklist	Autopilot pitch wheel down (P)
0	22_53	Run-In checklist	Dial Drop Alt+50 ft (P)
0	22_54	Run-In checklist	Slow to 130 KIAS
0	22_56	Run-In checklist	stop descent /level (J)
0	22_57	Run-In checklist	Run-in Checks (CP)
0.05	22_58	Run-In checklist	Complete, Copilot (CP)
0.05	22_6	Run-In checklist	Pass execute (FCI)
0.05	22_63	Run-In checklist	Clear to drop (DZ)
0.05	22_64	Run-In checklist	Acknowledge (P)
0.05	22_65	Run-In checklist	Acknowledge (CP)
0	22_66_0	Check Nav sys (CP)	START
0.15	22_66_2	Check Nav sys (CP)	Verify system position (CP)
0	22_66_3	Check Nav sys (CP)	Perform Update (CP)
0	22_66_999	Check Nav sys (CP)	END
0.05	22_67	Run-In checklist	Listen/record DZ winds (CP)
0.05	22_68	Run-In checklist	Listen DZ winds (P)
0	22_69	Run-In checklist	Relay drift FCI (J)

0.05	22_7	Run-In checklist	[callsign] slowdown, slow down, now	
0	22_70_0	Maintain In-track distance (P)	START	
0.15	22_70_6	Maintain In-track distance (P)	maintain drop airspeed (P)	
0.15	22_70_7	Maintain In-track distance (P)	maintain SKE in-track spacing (P)	
0	22_70_999	Maintain In-track distance (P)	END	
0	22_71	Run-In checklist	clear to deselect CMD RLY (P)	
0	22_72	Run-In checklist	Deselect CMD Relay (CP)	
0.05	22_73	Run-In checklist	CMD RELAY-OFF (CP)	
0.05	22_8	Run-In checklist	5 sec to slowdown (P)	
0	22_9	Run-In checklist	Relay 5 sec FCI (J)	
0	22_999	Run-In checklist	END	
0	24_0	Release Point Checklist	START	
0.05	24_10	Release Point Checklist	No drop (P)	
0.05	24_11	Release Point Checklist	No drop (CP)	
0.2	24_14	Release Point Checklist	Aircraft safe to drop? (P)	
0.2	24_15	Release Point Checklist	Aircraft safe to drop? (CP)	
0.05	24_2	Release Point Checklist	1 min (P)	
0.05	24_24	Release Point Checklist	5 sec (FCI)	
0.15	24_25	Release Point Checklist	Observe time (P)	
0.05	24_26	Release Point Checklist	5 sec (P)	
0	24_27	Release Point Checklist	Relay 5 sec FCI (J)	
0	24_28	Release Point Checklist	Passed (J)1	
0.05	24_29	Release Point Checklist	Execute (FCI)	
0	24_3	Release Point Checklist	Relay 1 min FCI (J)	
0.1	24_30	Release Point Checklist	Observe GL time (P)	
0.05	24_31	Release Point Checklist	Green Light! (P)	
0	24_32	Release Point Checklist	Relay "E" FCI (J)	
0	24_33	Release Point Checklist	turn on light (CP)	
0.05	24_34	Release Point Checklist	On! (CP)	
0.05	24_36	Release Point Checklist	Acknowledged, Copilot (CP)1	
0.05	24_37	Release Point Checklist	Acknowledged, Load (LM)1	
0	24_38	Release Point Checklist	Formation cleared to drop?	
0	24_39	Release Point Checklist	Formation safe to drop?	
0	24_4	Release Point Checklist	Passed (J)	
0.05	24_40	Release Point Checklist	Pass no drop (FCI)	
0.05	24_42	Release Point Checklist	xxxx, no drop, ack	
0.05	24_43	Release Point Checklist		2
0	24_44	Release Point Checklist	3 (P)	
0	24_45	Release Point Checklist	Jumpers exit	
0.05	24_46_0	Drop Malfunction	Pilot, malfunction (LM)	
0.05	24_46_1	Drop Malfunction	Brief description (LM)	
0	24_46_2	Drop Malfunction	Perform emergency actions (LM)	
0	24_46_3	Drop Malfunction	Perform emergency actions (P)	
0	24_46_4	Drop Malfunction	Perform emergency actions (CP)	
0	24_46_999	Drop Malfunction	END	
0	24_47	Release Point Checklist	Time for usable DZ (J)	
0.05	24_48	Release Point Checklist	load clear (LM)	
0.05	24_5	Release Point Checklist	Acknowledged, Load (LM)	

0.05	24_50	Release Point Checklist	Red light (P)
0	24_51	Release Point Checklist	turn off light (CP)
0.05	24_52	Release Point Checklist	on (CP)
0	24_53	Release Point Checklist	Time for 60 sec
0	24_55	Release Point Checklist	Computer drop switch (CP)
0.05	24_56	Release Point Checklist	Set, Auto, Pilot
0.05	24_57	Release Point Checklist	Set, Auto, Copilot
0	24_58_0	Fly to CARP (P)	START
0.15	24_58_2	Fly to CARP (P)	maintain SKE xtrk position (P)
0.15	24_58_3	Fly to CARP (P)	minimize SCNS xtrk (P)
0.15	24_58_4	Fly to CARP (P)	minimize TKE (P)
0.15	24_58_5	Fly to CARP (P)	maintain element drop altitude (P)
0.15	24_58_6	Fly to CARP (P)	maintain drop airspeed (P)
0.15	24_58_7	Fly to CARP (P)	maintain SKE in-track spacing (P)
0	24_58_999	Fly to CARP (P)	END
0	24_59	Release Point Checklist	Set computer drop switch (CP)
0.05	24_7	Release Point Checklist	1 min warn (FCI)
0	24_8	Release Point Checklist	Are jumpers safe?
0.05	24_9	Release Point Checklist	No drop (LM)
0	24_999	Release Point Checklist	END
0	25_0	Completion of Drop checklist	START
0	25_1	Completion of Drop checklist	Paratroop doors (CP)
0.05	25_11	Completion of Drop checklist	Accelerate, Accelerate now (P)
0	25_12	Completion of Drop checklist	set AC master switch (CP)
0	25_15	Completion of Drop checklist	add throttles (J)
0	25_16	Completion of Drop checklist	Pass "E" FCI (J)
0.05	25_17	Completion of Drop checklist	Flaps up (P)
0.05	25_18	Completion of Drop checklist	Flaps tracking up (CP)
0	25_19	Completion of Drop checklist	Move flap lever (CP)
0	25_2	Completion of Drop checklist	Close doors (LM)
0.05	25_21	Completion of Drop checklist	Flaps up (CP)
0.15	25_22	Completion of Drop checklist	Observe flaps 0% (CP)
0.05	25_3	Completion of Drop checklist	Closed and locked (LM)
0	25_32	Completion of Drop checklist	Select Computer drop switch-MAN (CP)
0	25_35	Completion of Drop checklist	switch off red light (CP)
0	25_37	Completion of Drop checklist	Drop checks (CP)
0.05	25_38	Completion of Drop checklist	Complete, Load (LM)
0.05	25_39	Completion of Drop checklist	Complete, Copilot
0	25_4	Completion of Drop checklist	close AD switch (CP)
0.05	25_40	Completion of Drop checklist	Pass 5 sec FCI
0.05	25_41	Completion of Drop checklist	Lead's 5 sec turn prep (P)
0.05	25_44	Completion of Drop checklist	Pass execute FCI
0.05	25_47	Completion of Drop checklist	Relay 5 sec FCI (P)
0	25_48	Completion of Drop checklist	Relay "E" FCI (J)
0.05	25_49	Completion of Drop checklist	L/R turn xxx (P)
0.05	25_5	Completion of Drop checklist	indicate closed (CP)
0.25	25_50	Completion of Drop checklist	monitor lead's position (CP)
0	25_51	Completion of Drop checklist	advance throttles (P)

0	25_52	Completion of Drop checklist	Accelerate 140 KIAS (P)
0	25_54	Completion of Drop checklist	Level @ new alt (J)
0	25_55	Completion of Drop checklist	Turn to escape heading (J)
0.25	25_56	Completion of Drop checklist	provide trend info to Pilot (CP)
0	25_57	Completion of Drop checklist	Roll out on course (J)
0.05	25_58	Completion of Drop checklist	Lead is lvl xxxx
0.05	25_59	Completion of Drop checklist	2 is level
0	25_6	Completion of Drop checklist	air deflector doors (CP)
0	25_60	Completion of Drop checklist	3 is level (P)
0.05	25_61	Completion of Drop checklist	Pass new IAS (FCI)
0	25_62	Completion of Drop checklist	Relay IAS FCI (J)
0.05	25_63	Completion of Drop checklist	New speed xxx (P)
0.05	25_64	Completion of Drop checklist	Pass 30 sec (FCI)1
0	25_65	Completion of Drop checklist	Relay 30 sec FCI (J)
0	25_66	Completion of Drop checklist	30 sec prep, Passed (J)
0	25_67	Completion of Drop checklist	Pass 5 sec (FCI)
0	25_68	Completion of Drop checklist	5 sec (J)
0	25_69	Completion of Drop checklist	Relay 5 sec FCI (J)
0	25_71	Completion of Drop checklist	Pass "E" (FCI)1
0	25_72	Completion of Drop checklist	accelerate
0	25_73	Completion of Drop checklist	adjust throttles (J)
0	25_74	Completion of Drop checklist	Adjust formation postn (J)1
0.05	25_75	Completion of Drop checklist	X PATH OFS, Set 0 (CP)
0.05	25_76	Completion of Drop checklist	VERT GDNC Set, ___ (CP)
0	25_77	Completion of Drop checklist	clear to select CMD RLY (P)
0	25_78	Completion of Drop checklist	select CMD Relay (CP)
0.05	25_79	Completion of Drop checklist	CMD RELAY-ON (CP)
0	25_80	Completion of Drop checklist	Dial Escape Alt (REF MODE) (P)
0	25_81	Completion of Drop checklist	Autopilot pitch wheel up (P)
0	25_82	Completion of Drop checklist	select CMD Relay (CP)1
0	25_999	Completion of Drop checklist	END
0	44_0	Freq change	START
0.05	44_1	Freq change	Direct freq change1
0.05	44_2	Freq change	Acknowledge (P)2
0	44_3	Freq change	Change radios (CP)1
0.05	44_4	Freq change	Check in1
0.05	44_5	Freq change	Acknowledge (P)3
0	44_999	Freq change	END
0	45_0	Freq change1	START
0.05	45_3	Freq change1	Obtain drop scores
0.05	45_4	Freq change1	Direct freq change
0.05	45_5	Freq change1	Acknowledge (P)
0	45_6	Freq change1	Change radios (CP)
0.05	45_7	Freq change1	Check in
0.05	45_8	Freq change1	Acknowledge (P)1
0.05	45_9	Freq change1	Copy drop scores (CP)
0	45_999	Freq change1	END
0	999	(Root)	Model END

Table 31: Task Listing and Tactical SA for Maximum Effort Airland (C-130H)

Tac SA Value	Task ID	Function	Task
0	0	(Root)	Model START
0	1_0	Descent checklist	START
0	1_1	Descent checklist	Compute TOLD card (E)
0	1_10	Descent checklist	SCNS LZ Data (E)
0.05	1_11	Descent checklist	Checked, Copilot (CP)
0.05	1_12	Descent checklist	Checked, Nav (N)
0	1_13	Descent checklist	Enter/verify LZ data (N)
0.1	1_14	Descent checklist	verify LZ data (CP)
0	1_15_0	Depressurize (E)	Is altitude appropriate?
0	1_15_2	Depressurize (E)	Wait
0	1_15_3	Depressurize (E)	Set cabin rate knob
0	1_15_4	Depressurize (E)	Set pressure controller
0	1_15_5	Depressurize (E)	set air cond master switch
0.15	1_15_999	Depressurize (E)	Cabin diff press =0
0	1_16	Descent checklist	Set fuel panel (E)
0	1_18	Descent checklist	Altimeters (E)
0	1_19	Descent checklist	set altimeter (N)
0	1_2	Descent checklist	Give card to CP (E)
0	1_20	Descent checklist	set altimeter (CP)
0	1_21	Descent checklist	set altimeter (P)
0.05	1_22	Descent checklist	state setting (P)
0.05	1_23	Descent checklist	state setting (CP)
0.05	1_24	Descent checklist	state setting, SCNS set (N)
0	1_25	Descent checklist	set SCNS altimeter (N)
0	1_26	Descent checklist	Radar altimeter (E)
0.05	1_27	Descent checklist	set radar altimeter (N)
0.05	1_28	Descent checklist	set radar altimeter (P)
0.05	1_29	Descent checklist	state setting (P) 1
0.1	1_3	Descent checklist	Check TOLD (CP)
0	1_30	Descent checklist	state setting(N)
0	1_31	Descent checklist	GCAS (E)
0	1_32	Descent checklist	set GCAS (CP)
0.05	1_33	Descent checklist	set, tactical (CP)
0	1_34	Descent checklist	Vert Ref switches (E)
0.05	1_35	Descent checklist	state setting (P)2
0.05	1_36	Descent checklist	state setting (CP)1
0	1_37	Descent checklist	set defensive systems (N)
0	1_38	Descent checklist	Defensive systems (E)
0.05	1_39	Descent checklist	state setting(N)1
0	1_4	Descent checklist	TOLD (E)
0	1_40	Descent checklist	Descent checks (E)
0.05	1_41	Descent checklist	Complete, Copilot (CP)

0.05	1_42	Descent checklist	Nav
0.05	1_43	Descent checklist	Load
0	1_44	Descent checklist	Retard throttles (P)
0	1_45	Descent checklist	Silence warning horn (CP)
0	1_46	Descent checklist	Disconnect autopilot (P)
0	1_47	Descent checklist	Call LZ (CP)
0.05	1_48	Descent checklist	Give Wx/rwy (ATC)
0.05	1_49	Descent checklist	Copy wx
0.05	1_5	Descent checklist	Checked (CP)
0.05	1_50	Descent checklist	Copy wx (E)
0	1_51	Descent checklist	Give Posit and appch request (CP)
0.05	1_52	Descent checklist	acknowledge/ approve entry (ATC)
0.05	1_53	Descent checklist	Report 2 way w/ LZ (N)
0.05	1_54	Descent checklist	acknowledge/approve frequency change (Tac ATC)
0	1_55	Descent checklist	Report release from Tac ATC (CP)
0	1_56	Descent checklist	Reach descent point
0	1_57	Descent checklist	Compute descent (P)
0	1_58	Descent checklist	Compute descent (CP)
0	1_59	Descent checklist	Compute descent (N)
0	1_6	Descent checklist	Crew, Descent checklist (P)
0.05	1_60	Descent checklist	Compare Data (P)
0.05	1_61	Descent checklist	Compare Data (CP)
0.05	1_62	Descent checklist	Compare Data (N)
0.05	1_63	Descent checklist	Listen to brief (CP)
0.05	1_64	Descent checklist	Listen to brief (N)
0	1_7	Descent checklist	Crew briefing (E)
0	1_8	Descent checklist	Brief arrival (P)
0.05	1_9	Descent checklist	Complete (P)
0.05	1_999	Descent checklist	Complete, Engineer
0.2	12	(Root)	Field in sight, copilot (CP)
0.2	13	(Root)	Field in sight, Pilot (P)
0	2_0	Before Landing checklist	START
0.05	2_1_0	Move flaps 50% (CP)	Flaps tracking 50% (CP)
0	2_1_10	Move flaps 50% (CP)	Move flaps to 30% (CP)
0.15	2_1_11	Move flaps 50% (CP)	Observe <190 KIAS (CP)
0	2_1_12	Move flaps 50% (CP)	Move flaps to 40% (CP)
0.15	2_1_13	Move flaps 50% (CP)	Observe <180 KIAS (CP)
0.15	2_1_2	Move flaps 50% (CP)	Observe <220 KIAS (CP)
0	2_1_3	Move flaps 50% (CP)	Move flaps to 50% (CP)
0.15	2_1_4	Move flaps 50% (CP)	Observe rudder hyrdaulic pressure increase (CP)
0.15	2_1_5	Move flaps 50% (CP)	Observe rudder hyrdaulic pressure increase (E)
0	2_1_6	Move flaps 50% (CP)	Move flaps to 10% (CP)
0.15	2_1_7	Move flaps 50% (CP)	Observe <210 KIAS (CP)
0	2_1_8	Move flaps 50% (CP)	Move flaps to 20% (CP)
0.15	2_1_9	Move flaps 50% (CP)	Observe <200 KIAS (CP)
0	2_1_999	Move flaps 50% (CP)	END
0	2_10	Before Landing checklist	Move gear handle (CP)
0.15	2_11	Before Landing checklist	Watch hydro px (CP)

0	2_12	Before Landing checklist	Before Landing checklist (P)
0	2_13	Before Landing checklist	Hot Mike (listen)
0	2_14	Before Landing checklist	Seat belt, shoulder harnesses (E)
0.05	2_15	Before Landing checklist	Fastened, unlocked, Pilot
0.05	2_16	Before Landing checklist	Copilot
0.05	2_17	Before Landing checklist	Engineer
0	2_18	Before Landing checklist	Altimeters (E)
0	2_19	Before Landing checklist	set altimeter (N)
0.05	2_2	Before Landing checklist	Flaps 50, on speed (P)
0	2_20	Before Landing checklist	set altimeter (CP)
0	2_21	Before Landing checklist	set altimeter (P)
0.05	2_22	Before Landing checklist	state setting (P)
0.05	2_23	Before Landing checklist	state setting (CP)
0.05	2_24	Before Landing checklist	state setting, SCNS set (N)
0	2_25	Before Landing checklist	set SCNS altimeter (N)
0.05	2_26	Before Landing checklist	set/read radar altimeter (N)
0.05	2_27	Before Landing checklist	set/read radar altimeter (P)
0	2_28	Before Landing checklist	Radar altimeter (E)
0	2_3	Before Landing checklist	Level at config altitude
0	2_31	Before Landing checklist	Flaps
0.05	2_32	Before Landing checklist	state flap setting (CP)
0	2_33	Before Landing checklist	Gear
0.15	2_34	Before Landing checklist	verify gear/ nose wheel (P)
0.05	2_35	Before Landing checklist	Down, indicators checked, Pilot
0.05	2_36	Before Landing checklist	Copilot1
0.15	2_37	Before Landing checklist	verify gear (CP)
0.15	2_38	Before Landing checklist	verify gear (E)
0.05	2_39	Before Landing checklist	Engineer1
0.05	2_4	Before Landing checklist	Flaps are 50% (CP)
0.1	2_40	Before Landing checklist	verify yaw damper disengaged (E)
0	2_41	Before Landing checklist	turn off syncrophaser (E)
0	2_42	Before Landing checklist	turn off underfloor heating (E)
0	2_43	Before Landing checklist	Landing Light panel
0	2_44	Before Landing checklist	Flip landing light switches
0	2_45	Before Landing checklist	lights on point
0.05	2_46	Before Landing checklist	Set (CP)
0	2_47	Before Landing checklist	hydraulic panel (E)
0.05	2_48	Before Landing checklist	Set (CP)1
0.15	2_49	Before Landing checklist	verify brake swtiches/pressures (CP)
0.15	2_5	Before Landing checklist	Observe <230 IAS (P)
0	2_50	Before Landing checklist	turn on aux pump (CP)
0	2_51	Before Landing checklist	Flip Antiskid test switch (E)
0.1	2_52	Before Landing checklist	Observe Antiskid test lights (E)
0	2_53	Before Landing checklist	Before Landing checks (E)
0.05	2_54	Before Landing checklist	Complete, Copilot

0.05	2_55	Before Landing checklist	Nav
0.05	2_56	Before Landing checklist	Load
0.05	2_57	Before Landing checklist	Complete, Engineer (E)
0.15	2_58	Before Landing checklist	Observe <145 KIAS (P)
0.05	2_59	Before Landing checklist	Flaps 100% (P)
0.15	2_6	Before Landing checklist	Observe <165 KIAS (P)
0.15	2_60	Before Landing checklist	Observe <145 KIAS (CP)
0	2_61	Before Landing checklist	Move flaps to 100% (CP)
0.05	2_62	Before Landing checklist	Flaps tracking 100% (CP)
0	2_63	Before Landing checklist	Adjust throttles (P)
0	2_65	Before Landing checklist	slow to threshold speed (P) Flaps set 100% (CP)
			2_68 Before Landing checklist descend @ final approach (P)
			2_69 Before Landing checklist adjust defensive systems (N)
			2_7 Before Landing checklist Command gear down
0.05	2_67	Before Landing checklist	2_70 Before Landing checklist Give winds / Clear to Land" (ATC)
0.05	2_71	Before Landing checklist	Cleared to land (CP)
0.05	2_72	Before Landing checklist	Gear down (CP)
0	2_73	Before Landing checklist	Slowdown/trim (P)
0.05	2_74	Before Landing checklist	1000 Above (CP)
0	2_75	Before Landing checklist	Pull hot mike knob (P)
0	2_76	Before Landing checklist	Pull hot mike knob (CP)
0.05	2_77	Before Landing checklist	Pilot is hot mike (P)
0.05	2_78	Before Landing checklist	Copilot is hot mike (CP)
0.15	2_8	Before Landing checklist	Verify <165 KIAS (CP)
0.05	2_9	Before Landing checklist	Speed's good, gear down (CP)
0	2_999	Before Landing checklist	END
0	4_0	On the runway	START
0.05	4_1_0	Airspeed/Altitude sing-song	50 feet (N)
0.05	4_1_1	Airspeed/Altitude sing-song	State speed & descent rate (CP)
0	4_1_10	Airspeed/Altitude sing-song	Adjust throttles (P)
0.05	4_1_2	Airspeed/Altitude sing-song	40 (N)
0.05	4_1_3	Airspeed/Altitude sing-song	State speed & descent rate (CP)1
0.05	4_1_4	Airspeed/Altitude sing-song	30 (N)
0.05	4_1_5	Airspeed/Altitude sing-song	State speed & descent rate (CP)2
0.05	4_1_6	Airspeed/Altitude sing-song	20 (N)
0.05	4_1_7	Airspeed/Altitude sing-song	State speed & descent rate (CP)3
0.05	4_1_8	Airspeed/Altitude sing-song	10 (N)
0	4_1_9	Airspeed/Altitude sing-song	Adjust pitch (P)
0	4_1_999	Airspeed/Altitude sing-song	END
0.05	4_10	On the runway	Going around (P)
0	4_100	On the runway	Offload/Onload (LM)

0.15	4_101	On the runway	Safety Observe (N)
0	4_102	On the runway	Run locks (N)
0.05	4_103	On the runway	Relay upload weight (LM)
0	4_104	On the runway	Compute TOLD (E)
0	4_105	On the runway	Post TOLD (E)
0.1	4_106	On the runway	Check TOLD (CP)
0.05	4_107	On the runway	Clear to taxi (LM)
0	4_108	On the runway	Return to seat (N)
0	4_109	On the runway	Interphone/PA (E)1
0	4_110	On the runway	flip PA switch (P)1
0	4_111	On the runway	flip PA switch (N)1
0.05	4_112	On the runway	set, Pilot1
0.05	4_113	On the runway	Copilot2
0.05	4_114	On the runway	Nav2
0.05	4_116	On the runway	Engineer2
0	4_117	On the runway	ERO Ops Stop checks (E)
0.05	4_118	On the runway	Complete, Load
0.05	4_119	On the runway	Engineer3
0	4_120	On the runway	Release parking brake (P)
0.05	4_121	On the runway	Clear to up speed a pair (P)
0.05	4_122	On the runway	Inboards coming up (E)
0	4_123	On the runway	pull LGSI buttons (E)2
0.15	4_124	On the runway	Observe upspeed (E)
0.15	4_125	On the runway	Observe upspeed (CP)
0.2	4_126	On the runway	Taxi (P)
0.05	4_127	On the runway	Flaps 50
0.05	4_130	On the runway	Flaps tracking 50% (CP)1
0	4_131	On the runway	Move flaps to 50% (CP)1
0	4_132	On the runway	Set take off trim (CP)
0	4_133	On the runway	Set exterior lights (CP)
0	4_134	On the runway	Set exterior lights (CP)1
0	4_135	On the runway	Lights (P)
0	4_136	On the runway	Set exterior lights (CP)2
0	4_143_0	Go Around	START
0	4_143_1	Go Around	Add power (P)
0	4_143_10	Go Around	Turn to final
0	4_143_15	Go Around	Announce go around / request closed (CP)
0.05	4_143_16	Go Around	Clear to closed pattern (ATC)
0.05	4_143_17	Go Around	Acknowledge clearance (CP)
0.15	4_143_18	Go Around	Observe <145 KIAS (P)
0.05	4_143_19	Go Around	Flaps 100% (P)
0	4_143_2	Go Around	Climb to altitude (P)
0.15	4_143_20	Go Around	Observe <145 KIAS (CP)
0	4_143_21	Go Around	Move flaps to 100% (CP)1
0.05	4_143_22	Go Around	Flaps tracking 100% (CP)
0	4_143_23	Go Around	Reduce throttles (P)1
0.05	4_143_29	Go Around	Report base turn w/ gear (CP)
0.05	4_143_3	Go Around	Flaps tracking 50% (CP)

0.05	4_143_30	Go Around	Give winds / "Clear to Land" (ATC)
0.05	4_143_31	Go Around	Cleared to land (CP)
0	4_143_32	Go Around	Turn to closed pattern (P)
0.05	4_143_33	Go Around	Leaving gear and flaps, after takeoff touch and go checklist (P)
0.05	4_143_34	Go Around	Checklist (E)
0	4_143_35	Go Around	Crew Briefing (P)
0.05	4_143_36	Go Around	Listen (CP)
0.05	4_143_37	Go Around	Listen (N)
0.05	4_143_38	Go Around	Listen (E)
0	4_143_4	Go Around	Move flaps to 50% (CP)
0	4_143_40	Go Around	Before Landing Touch and Go Checklist (P)
0.05	4_143_41	Go Around	Checklist (E)1
0.05	4_143_42	Go Around	Checklist (CP)
0.05	4_143_43	Go Around	Checklist (P)
0.05	4_143_5	Go Around	Flaps 50
0	4_143_7	Go Around	Level at altitude
0	4_143_9	Go Around	adjust throttles (P)
0	4_143_999	Go Around	END
0.05	4_144	On the runway	Give taxi instructions
0.05	4_145	On the runway	Read back (CP)
0	4_146	On the runway	Coordinate departure (CP)
0.05	4_147	On the runway	Coordinate departure (ATC)
0	4_148	On the runway	Request taxi (CP)
0.05	4_149	On the runway	Give taxi instructions
0.05	4_150	On the runway	Read back (CP)1
0.05	4_151	On the runway	Listen (CP)
0.05	4_152	On the runway	Listen (N)
0.05	4_153	On the runway	Listen (E)
0.2	4_2	On the runway	Observe aimpoint (CP)
0.2	4_29	On the runway	Check for asymmetric thrust (P)
0.05	4_3	On the runway	direct pilot corrections (CP)
0.15	4_30	On the runway	Check for asymmetric thrust (E)
0.05	4_31	On the runway	Cleared reverse (E)
0	4_32	On the runway	Apply brakes (P)
0.15	4_33	On the runway	Verify <115 KIAS
0.15	4_34	On the runway	Verify <115 KIAS (E)
0.05	4_35	On the runway	Copilot's yoke (P)
0.05	4_36	On the runway	Copilot's yoke (CP)
0.2	4_37	On the runway	Maintain wings level (CP)
0	4_38	On the runway	Steer with tiller wheel (P)
0	4_39	On the runway	Move throttles to Max reverse (P)
0.2	4_4	On the runway	Make corrections (P)
0.15	4_40	On the runway	Observe 60 KIAS (CP)
0.05	4_41	On the runway	60 (CP)
0	4_42	On the runway	Move throttles out of reverse (P)
0.05	4_43	On the runway	40 (CP)
0	4_44	On the runway	Throttles-ground idle (P)1
0.2	4_45	On the runway	Slow to taxi speed (P)

0.05	4_46	On the runway	Clear to down- speed outboards (P)
0.15	4_47	On the runway	verify <30 knots (E)
0.05	4_48	On the runway	Outboards coming down (E)
0	4_49	On the runway	press LGSI buttons (E)
0	4_5	On the runway	Reduce throttles (P)
0.15	4_50	On the runway	Observe downspeed (E)
0.15	4_51	On the runway	Observe downspeed (CP)
0	4_52	On the runway	Start APU (E)
0	4_53	On the runway	ERO Ops stop checklist
0	4_54	On the runway	Safe defensive system (N)
0	4_55	On the runway	Radar-standby (N)
0	4_56	On the runway	Set AC 'No Press' (E)
0	4_57	On the runway	Clear to open ramp/door (P)
0	4_58	On the runway	Nav panel (E)
0.05	4_59	On the runway	set (N)
0.2	4_6	On the runway	Flare aircraft (P)
0	4_60	On the runway	Set APU/ electrical panel (E)
0.05	4_61	On the runway	Clear to down speed inboards? (E)
0	4_62	On the runway	Roger (LM)
0	4_63	On the runway	Open ramp/door (LM)
0.1	4_64	On the runway	Observe door open light (P)
0	4_65	On the runway	Clear (P)
0.05	4_66	On the runway	Inboards coming down (E)1
0	4_67	On the runway	press LGSI buttons (E)1
0.15	4_68	On the runway	Observe downspeed (E)1
0.15	4_69	On the runway	Observe downspeed (CP)1
0	4_7	On the runway	Throttles-ground idle (P)
0	4_70	On the runway	Set anti-icing panel (E)
0.2	4_71	On the runway	Turn off of runway (P)
0	4_72	On the runway	Crew briefing (E)
0	4_73	On the runway	Brief crew (P)
0.2	4_74	On the runway	Taxi to park (P)
0.2	4_75	On the runway	Brake to stop (P)
0.05	4_76	On the runway	complete (P)
0	4_77	On the runway	Set parking brake (P)
0	4_78	On the runway	Parking brake (E)
0.05	4_79	On the runway	set (P)
0.2	4_8	On the runway	Touchdown
0	4_80	On the runway	Hot Mike (E)
0.05	4_81	On the runway	on, Pilot
0.05	4_82	On the runway	Copilot
0.05	4_83	On the runway	Nav
0.05	4_84	On the runway	Engineer
0	4_85	On the runway	Interphone/PA (E)
0	4_86	On the runway	flip PA switch (P)
0	4_87	On the runway	flip PA switch (N)
0.05	4_88	On the runway	Checked, Pilot
0.05	4_89	On the runway	Copilot1

0.05	4_9	On the runway	Go around (CP)
0.05	4_90	On the runway	Nav1
0.05	4_91	On the runway	Load
0.05	4_92	On the runway	Engineer1
0	4_93	On the runway	Move to Safety position (N)
0	4_94	On the runway	Safety Observer (E)
0.05	4_95	On the runway	In position (N)
0	4_96	On the runway	Doors
0.05	4_97	On the runway	Clear to open ramp/door (P)1
0	4_98	On the runway	Offload/Onload clearance (E)
0.05	4_99	On the runway	Clear to offload/onload (P)2
0	4_999	On the runway	END
0	8	(Root)	Give Posit (CP)
0.05	9	(Root)	Request posit (ATC)
0	999	(Root)	Model END

Table 32: Task Listing and Tactical SA Values for Maximum Effort Airland (C-130J)

Tac SA Value	Task ID	Function	Task
0	1_0	Approach checklist	START
0	1_1	Approach checklist	Program TOLD (CP)
0	1_10	Approach checklist	CNI-MU Data (CP)
0.05	1_11	Approach checklist	Checked, Copilot (CP)
0.05	1_12	Approach checklist	Checked, Pilot (P)
0	1_13	Approach checklist	Program CNI-MU
0.1	1_14	Approach checklist	verify LZ data (P)
0	1_15_0	Depressurize (CP)	Is altitude appropriate?
0	1_15_3	Depressurize (CP)	Set cabin rate knob
0	1_15_4	Depressurize (CP)	Set pressure controller
0	1_15_5	Depressurize (CP)	set air cond master switch
0	1_15_999	Depressurize (CP)	END
0	1_16	Approach checklist	Set fuel panel (CP)
0	1_18	Approach checklist	Altimeters (CP)
0.1	1_2	Approach checklist	Read TOLD (P)
0	1_20	Approach checklist	set altimeter (CP)
0	1_21	Approach checklist	set altimeter (P)
0.05	1_22	Approach checklist	state setting (P)
0.05	1_23	Approach checklist	state setting (CP)
0	1_26	Approach checklist	TOLD (CP)
0	1_27	Approach checklist	set radar altimeter (CP)
0	1_28	Approach checklist	set radar altimeter (P)
0.05	1_29	Approach checklist	Reviewed, Pilot (P)
0.05	1_30	Approach checklist	Reviewed, Copilot (CP)
0	1_32	Approach checklist	set GCAS (CP)
0	1_37	Approach checklist	set defensive systems (CP)
0	1_4	Approach checklist	Approach setup (CP)
0	1_40	Approach checklist	Approach checks (CP)
0.05	1_43	Approach checklist	Complete Load
0	1_44	Approach checklist	Retard throttles (P)
0	1_45	Approach checklist	Silence warning horn (CP)
0	1_46	Approach checklist	Disconnect autopilot (P)
0	1_47	Approach checklist	Call LZ (CP)
0.05	1_48	Approach checklist	Give Wx/rwy (ATC)
0.05	1_49	Approach checklist	Copy wx
0.05	1_5	Approach checklist	Copilot (CP)
0	1_51	Approach checklist	Give Posit and appch request (CP)
0.05	1_52	Approach checklist	acknowledge/ approve entry (ATC)
0.05	1_53	Approach checklist	Report 2 way w/ LZ (P)
0.05	1_54	Approach checklist	acknowledge/approve frequency change (Tac ATC)
0.05	1_55	Approach checklist	Report release from Tac ATC (CP)
0	1_56	Approach checklist	Reach descent point
0	1_57	Approach checklist	Compute descent (P)

0	1_58		Approach checklist	Compute descent (CP)
0	1_6		Approach checklist	Crew, Approach checklist (P)
0.05	1_60		Approach checklist	Compare Data (P)
0.05	1_61		Approach checklist	Compare Data (CP)
0.05	1_63		Approach checklist	Listen to brief (CP)
0	1_64		Approach checklist	Configure HUD/REF MODE/CNBP/AMU (P)
0	1_65		Approach checklist	Configure HUD/REF MODE/CNBP/AMU (CP)
0	1_66		Approach checklist	set stby altimeter (P)1
0.05	1_67		Approach checklist	Complete (P)
0	1_68		Approach checklist	Seat belt, shoulder harnesses (CP)
0.05	1_69		Approach checklist	Fastened, unlocked, Pilot
0	1_7		Approach checklist	Crew briefing (CP)
0.05	1_70		Approach checklist	Copilot
0	1_8		Approach checklist	Brief arrival (P)
0.05	1_9		Approach checklist	Complete, Pilot (P)
0.05	1_999		Approach checklist	Complete, Copilotr
0.2		12	(Root)	Field in sight, copilot (CP)
0.2		13	(Root)	Field in sight, Pilot (P)
0	2_0		Before Landing checklist	START
0	2_1_0		Move flaps 50% (CP)	START
0.15	2_1_11		Move flaps 50% (CP)	Observe <190 KIAS (CP)
0.15	2_1_13		Move flaps 50% (CP)	Observe <180 KIAS (CP)
0.05	2_1_14		Move flaps 50% (CP)	Flaps tracking 50% (CP)
0.05	2_1_15		Move flaps 50% (CP)	Flaps 50, on speed (P)
0.15	2_1_16		Move flaps 50% (CP)	Observe <190 KIAS (P)
0.15	2_1_17		Move flaps 50% (CP)	Observe <180 KIAS (P)
0.15	2_1_18		Move flaps 50% (CP)	Observe <220 KIAS (P)
0.15	2_1_19		Move flaps 50% (CP)	Observe <210 KIAS (P)
0.15	2_1_2		Move flaps 50% (CP)	Observe <220 KIAS (CP)
0.15	2_1_20		Move flaps 50% (CP)	Observe <200 KIAS (P)
0	2_1_3		Move flaps 50% (CP)	Move flaps to 50% (CP)
0.15	2_1_4		Move flaps 50% (CP)	Observe rudder hyrdaulic pressure increase (CP)
0.15	2_1_7		Move flaps 50% (CP)	Observe <210 KIAS (CP)
0.15	2_1_9		Move flaps 50% (CP)	Observe <200 KIAS (CP)
0	2_1_999		Move flaps 50% (CP)	END
0	2_10		Before Landing checklist	Move gear handle (CP)
0.15	2_11		Before Landing checklist	Watch hydro px (CP)
0	2_12		Before Landing checklist	Before Landing checklist (P)
0	2_3		Before Landing checklist	Level at config altitude
0	2_33		Before Landing checklist	Gear
0.15	2_34		Before Landing checklist	verify gear/ nose wheel (CP)
0.05	2_35		Before Landing checklist	Down, indicators checked, Copilot
0.05	2_36		Before Landing checklist	Pilot1
0.15	2_37		Before Landing checklist	verify gear (P)
0.05	2_4		Before Landing checklist	Flaps are 50% (CP)
0	2_44		Before Landing checklist	Flip landing light switches
0	2_45		Before Landing checklist	lights on point
0.15	2_49		Before Landing checklist	verify brake swtiches/pressures (CP)

0.15	2_5	Before Landing checklist	Observe <230 IAS (P)
0	2_50	Before Landing checklist	turn on aux pump (CP)
0.1	2_52	Before Landing checklist	Check for Anti- skid Error msg (CP)
0	2_53	Before Landing checklist	Before Landing checks (CP)
0.05	2_54	Before Landing checklist	Complete, Copilot
0.05	2_55	Before Landing checklist	state setting
0.05	2_56	Before Landing checklist	Load
0.15	2_58	Before Landing checklist	Observe <145 KIAS (P)
0.05	2_59	Before Landing checklist	Flaps 100% (P)
0.15	2_6	Before Landing checklist	Observe <165 KIAS (P)
0.15	2_60	Before Landing checklist	Observe <145 KIAS (CP)
0	2_61	Before Landing checklist	Move flaps to 100% (CP)
0.05	2_62	Before Landing checklist	Flaps tracking 100% (CP)
0	2_63	Before Landing checklist	Adjust throttles (P)
0	2_65	Before Landing checklist	slow to threshold speed (P) Flaps set 100% (CP)
			2_68 Before Landing checklist descend @ final approach (P)
			2_69 Before Landing checklist adjust defensive systems (CP)
			2_7 Before Landing checklist Command gear down
variable	2_67	Before Landing checklist	2_70 Before Landing checklist Give winds / Clear to Land" (ATC)
0.05	2_71	Before Landing checklist	Cleared to land (CP)
0.05	2_72	Before Landing checklist	Gear down (CP)
0	2_73	Before Landing checklist	Slowdown/trim (P)
0.05	2_74	Before Landing checklist	1000 Above (CP)
0	2_79	Before Landing checklist	Reset HUD FPA (P)
0.15	2_8	Before Landing checklist	Verify <165 KIAS (CP)
0.05	2_80	Before Landing checklist	HUD reset X deg (P)
0.05	2_9	Before Landing checklist	Speed's good, gear down (CP)
0	2_999	Before Landing checklist	END
0	4_0	On the runway	START
0.05	4_1_0	Airspeed/Altitude sing-song	50 feet (CP)
0	4_1_1	Airspeed/Altitude sing-song	Delay
0	4_1_10	Airspeed/Altitude sing-song	Adjust throttles (P)
0.05	4_1_2	Airspeed/Altitude sing-song	40 (CP)
0	4_1_3	Airspeed/Altitude sing-song	Delay1
0.05	4_1_4	Airspeed/Altitude sing-song	30 (CP)
0	4_1_5	Airspeed/Altitude sing-song	Delay2
0.05	4_1_6	Airspeed/Altitude sing-song	20 (CP)
0	4_1_7	Airspeed/Altitude sing-song	Delay3
0.05	4_1_8	Airspeed/Altitude sing-song	10 (CP)
0	4_1_9	Airspeed/Altitude sing-song	Adjust pitch (P)
0	4_1_999	Airspeed/Altitude sing-song	END

0.05	4_10	On the runway	Going around (P)
0	4_100	On the runway	Offload/Onload (LM)
0	4_102	On the runway	Run locks (LM)
0.05	4_103	On the runway	Relay upload weight (LM)
0	4_104	On the runway	Program TOLD (CP)
0.1	4_106	On the runway	Check TOLD (P)
0.05	4_107	On the runway	Ready for taxi (LM)
0	4_117	On the runway	ERO checks (CP)
0.05	4_118	On the runway	Complete, Load
0.05	4_119	On the runway	Copilot
0	4_120	On the runway	Release parking brake (P)
0.05	4_121	On the runway	Clear to up speed a pair (P)
0.05	4_122	On the runway	Inboards coming up (CP)
0	4_123	On the runway	pull LGSI buttons (CP)2
0.15	4_125	On the runway	Observe upspeed (CP)
0.2	4_126	On the runway	Taxi (P)
0.05	4_127	On the runway	Flaps 50
0.05	4_130	On the runway	Flaps tracking 50% (CP)1
0	4_131	On the runway	Move flaps to 50% (CP)1
0	4_132	On the runway	Set take off trim (CP)
0	4_133	On the runway	Set exterior lights (CP)
0	4_134	On the runway	Set exterior lights (CP)1
0	4_135	On the runway	Lights (P)
0	4_136	On the runway	Set exterior lights (CP)2
0	4_143_0	Go Around	START
0	4_143_1	Go Around	Add power (P)
0	4_143_10	Go Around	Turn to final
0.05	4_143_15	Go Around	Announce go around / request closed (CP)
0.05	4_143_16	Go Around	Clear to closed pattern (ATC)
0.05	4_143_17	Go Around	Acknowledge clearance (CP)
0.15	4_143_18	Go Around	Observe <145 KIAS (P)
0.05	4_143_19	Go Around	Flaps 100% (P)
0	4_143_2	Go Around	Climb to altitude (P)
0.15	4_143_20	Go Around	Observe <145 KIAS (CP)
0	4_143_21	Go Around	Move flaps to 100% (CP)1
0.05	4_143_22	Go Around	Flaps tracking 100% (CP)
0	4_143_23	Go Around	Reduce throttles (P)1
0.05	4_143_29	Go Around	Report base turn w/ gear (CP)
0.05	4_143_3	Go Around	Flaps tracking 50% (CP)
0.05	4_143_30	Go Around	Give winds / "Clear to Land" (ATC)
0.05	4_143_31	Go Around	Cleared to land (CP)
0	4_143_32	Go Around	Turn to closed pattern (P)
0.05	4_143_33	Go Around	Leaving gear and flaps, after takeoff touch and go checklist (P)
0.05	4_143_34	Go Around	Checklist
0	4_143_35	Go Around	Crew Briefing (P)
0.05	4_143_36	Go Around	Listen (CP)
0	4_143_4	Go Around	Move flaps to 50% (CP)
0	4_143_40	Go Around	Before Landing Touch and Go Checklist (P)

0.05	4_143_41	Go Around	Checklist (CP)1
0.05	4_143_42	Go Around	Checklist (CP)
0.05	4_143_43	Go Around	Checklist (P)
0.05	4_143_5	Go Around	Flaps 50
0	4_143_7	Go Around	Level at altitude
0	4_143_9	Go Around	adjust throttles (P)
0	4_143_999	Go Around	END
0.05	4_144	On the runway	Give taxi instructions
0.05	4_145	On the runway	Read back (CP)
0	4_146	On the runway	Coordinate departure (CP)
0.05	4_147	On the runway	Coordinate departure (ATC)
0	4_148	On the runway	Request taxi (CP)
0.05	4_149	On the runway	Give taxi instructions
0.05	4_150	On the runway	Read back (CP)1
0.05	4_151	On the runway	Listen (CP)
0.05	4_152	On the runway	Def Sys set Stby (CP)
0	4_153	On the runway	Test open Swing window (P)
0	4_154	On the runway	Program CNI-MU
0	4_155	On the runway	Configure HUD/REF MODE/CNBP/AMU (CP)
0	4_156	On the runway	Configure HUD/REF MODE/CNBP/AMU (P)
0.05	4_157	On the runway	Hotel Mode (CP)
0	4_158	On the runway	Propeller control switches (CP)
0.15	4_159	On the runway	Observe downspeed (CP)2
0	4_160	On the runway	Propeller control switches (CP)1
0.15	4_161	On the runway	Observe upspeed (CP)
0.05	4_162	On the runway	Departure setup, complete Copilot
0.05	4_163	On the runway	Pilot
0.05	4_164	On the runway	CNI-MU checked Copilot
0.05	4_165	On the runway	Pilot1
0.05	4_166	On the runway	Listen (CP)1
0	4_167	On the runway	Departure briefing (CP)
0	4_168	On the runway	Brief crew (P)1
0.05	4_169	On the runway	complete (P)1
0	4_170	On the runway	Shut down APU (CP)
0	4_171	On the runway	Set APU/ electrical panel (CP)1
0	4_172	On the runway	Arm defensive system (CP)1
0.05	4_173	On the runway	Def Sys set Stby (CP)1
0.15	4_174	On the runway	Look at brake panel (CP)
0.05	4_175	On the runway	Brakes set normal (CP)
0.05	4_176	On the runway	LGSI switches set, normal (CP)
0.15	4_177	On the runway	Look at flap gauge (CP)
0.05	4_178	On the runway	Flaps set 50% (CP)
0.15	4_179	On the runway	Look at trim gauge (CP)
0.05	4_180	On the runway	Trim set (CP)
0.2	4_2	On the runway	Observe aimpoint (CP)
0.2	4_29	On the runway	Check for asymmetric thrust (P)
0.05	4_3	On the runway	direct pilot corrections (CP)
0.15	4_30	On the runway	Observe BETA indication (CP)

0.05	4_31	On the runway	4 B's (CP)
0	4_32	On the runway	Apply brakes (P)
0.15	4_33	On the runway	Verify <145 KTAS
0.15	4_34	On the runway	Verify <145 KIAS (CP)
0.05	4_35	On the runway	Copilot's yoke (P)
0.05	4_36	On the runway	Copilot's yoke (CP)
0.2	4_37	On the runway	Maintain wings level (CP)
0	4_38	On the runway	Steer with tiller wheel (P)
0	4_39	On the runway	Move throttles to Max reverse (P)
0.2	4_4	On the runway	Make corrections (P)
0.15	4_40	On the runway	Observe 60 KIAS (CP)
0.05	4_41	On the runway	60 (CP)
0	4_42	On the runway	Move throttles out of reverse (P)
0.05	4_43	On the runway	40 (CP)
0	4_44	On the runway	Throttles-ground idle (P)1
0.2	4_45	On the runway	Slow to taxi speed (P)
0.05	4_46	On the runway	Clear to down- speed outboards (P)
0.15	4_47	On the runway	verify <30 knots (CP)
0.05	4_48	On the runway	Outboards coming down (CP)
0	4_49	On the runway	press LGSI buttons (CP)
0	4_5	On the runway	Reduce throttles (P)
0.15	4_51	On the runway	Observe downspeed (CP)
0	4_52	On the runway	Start APU (CP)
0	4_53	On the runway	ERO Ops stop checklist
0	4_54	On the runway	Safe defensive system (CP)
0	4_56	On the runway	Set AC 'No Press' (CP)
0	4_57	On the runway	Clear to open ramp/door (P)
0.2	4_6	On the runway	Flare aircraft (P)
0	4_60	On the runway	Set APU/ electrical panel (CP)
0.05	4_61	On the runway	Clear to down speed inboards? (CP)
0	4_62	On the runway	Roger (LM)
0	4_63	On the runway	Open ramp/door (LM)
0.1	4_64	On the runway	Observe door open light (P)
0	4_65	On the runway	Clear (P)
0.05	4_66	On the runway	Inboards coming down (CP)1
0	4_67	On the runway	press LGSI buttons (CP)1
0.15	4_69	On the runway	Observe downspeed (CP)1
0	4_7	On the runway	Throttles- ground idle (P)
0.2	4_71	On the runway	Turn off of runway (P)
0	4_72	On the runway	Crew briefing (CP)
0.05	4_73	On the runway	Brief crew (P)
0.2	4_74	On the runway	Taxi to park (P)
0.2	4_75	On the runway	Brake to stop (P)
0.05	4_76	On the runway	complete (P)
0	4_77	On the runway	Set parking brake (P)
0.2	4_8	On the runway	Touchdown
0.05	4_9	On the runway	Go around (CP)
0	4_98	On the runway	Offload/Onload clearance (CP)

0.05	4_99	On the runway	Clear to offload/onload (P)
0	4_999	On the runway	END
0	8	(Root)	Give Posit (CP)
0.05	9	(Root)	Request posit (ATC)
0	999	(Root)	Model END

Appendix E: UML Activity Diagrams

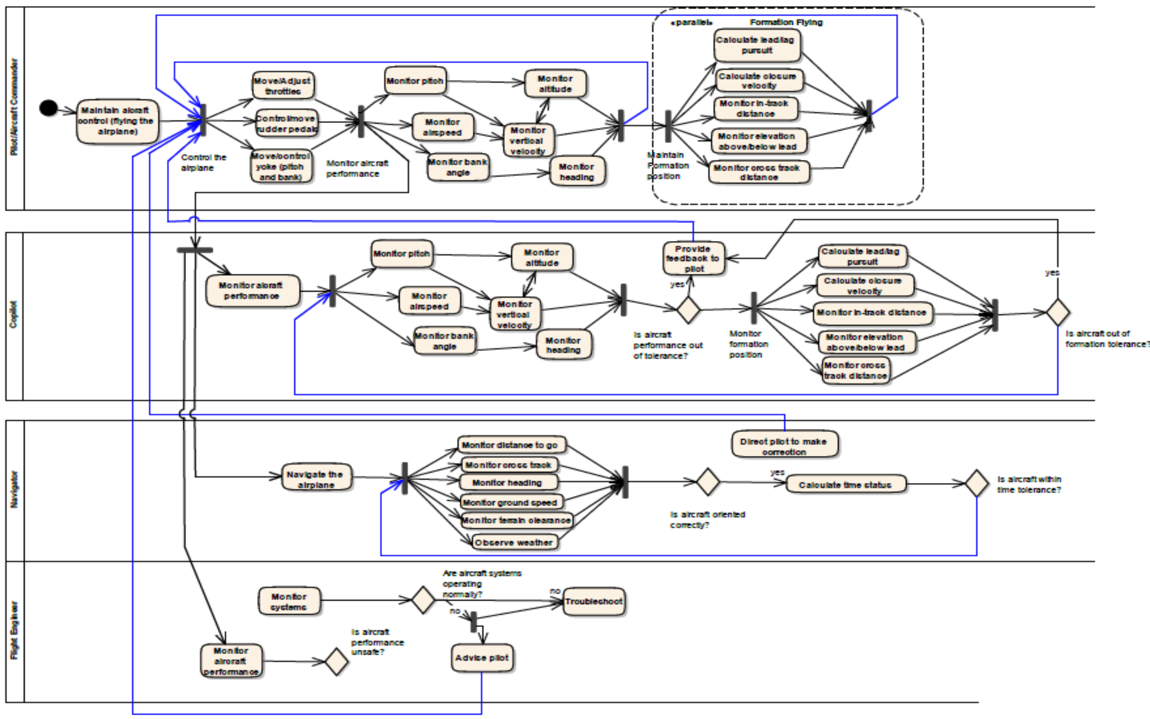

Figure 36: Basic Aircraft Control UML Activity Diagram

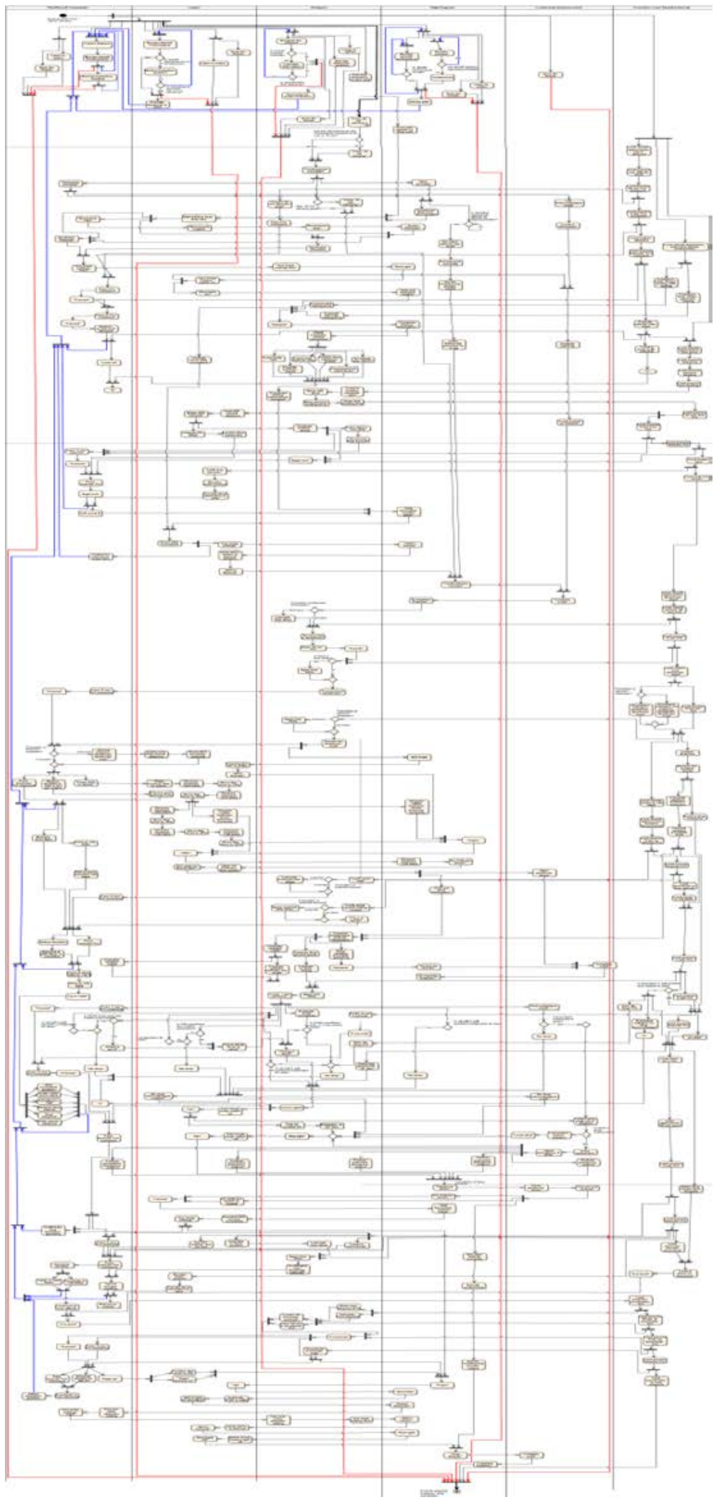

Figure 37: SKE Formation Airdrop UML Activity Diagram

Appendix F: IMPRINT Task Networks

Basic Aircraft Control

C-130H

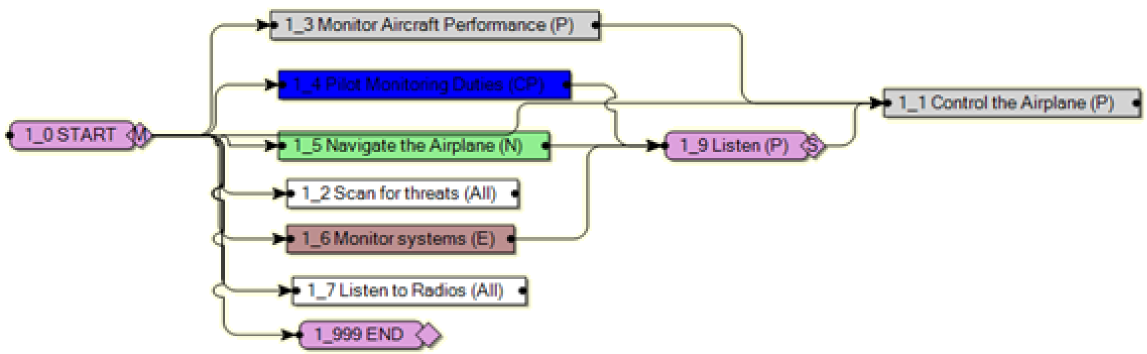

Figure 38: Basic Aircraft Control Task Network (C-130H)

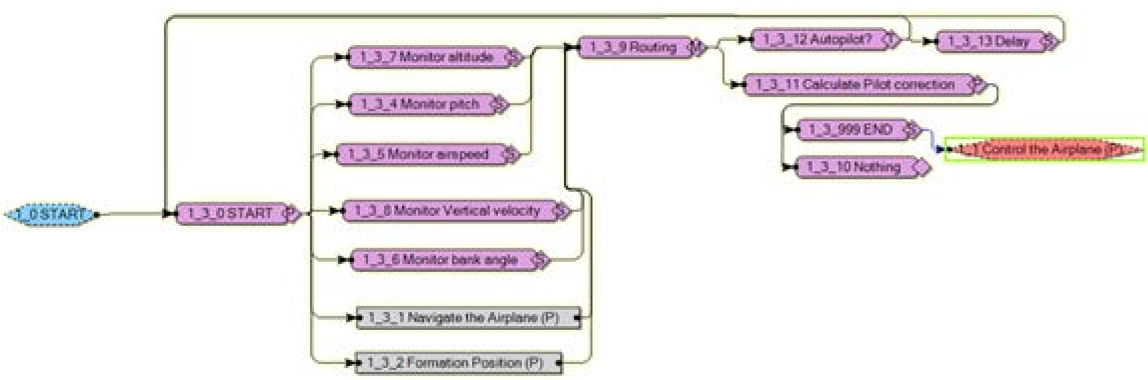

Figure 39: Monitor Aircraft Performance (P) Function (C-130H)

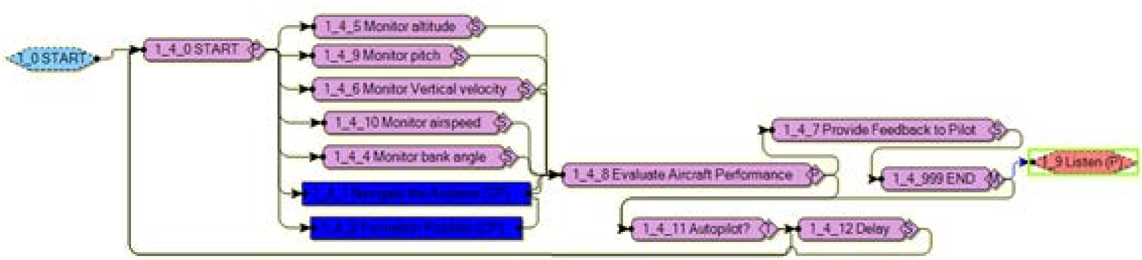

Figure 40: Pilot Monitoring Duties (CP) Function (C-130H)

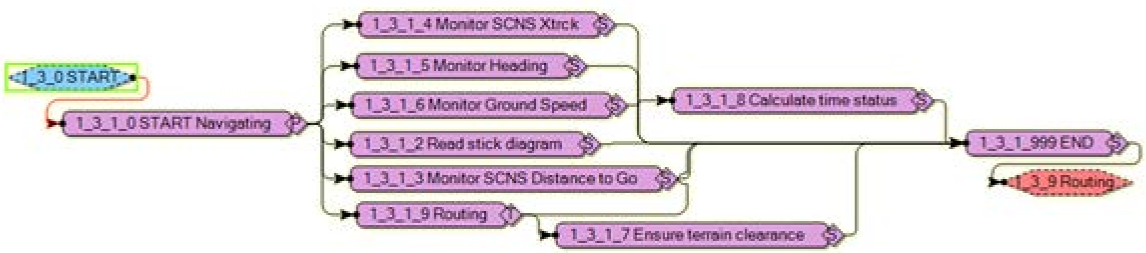

Figure 41: Navigate the Airplane (P/CP) Function (C-130H)

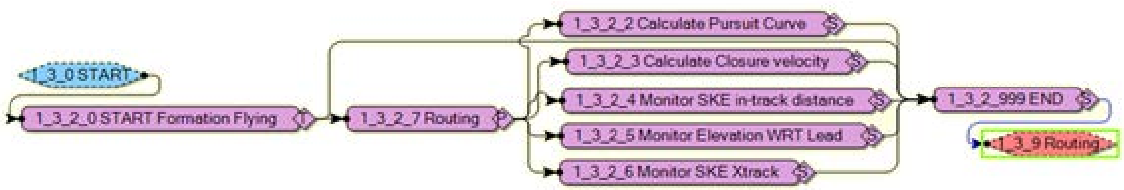

Figure 42: Formation Position (P/CP) Function (C-130H)

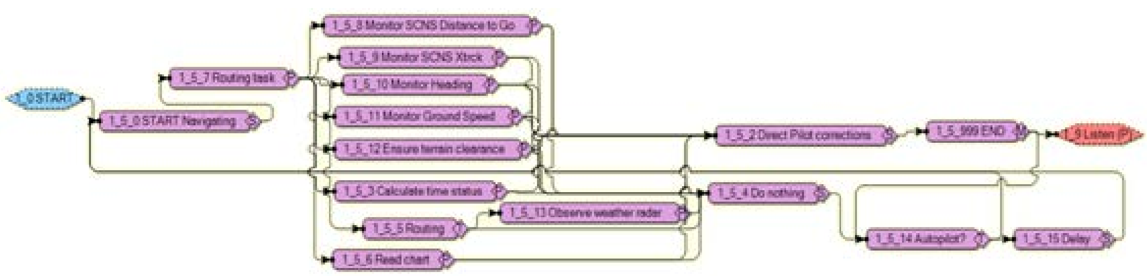

Figure 43: Navigate the Airplane (N) Function (C-130H)

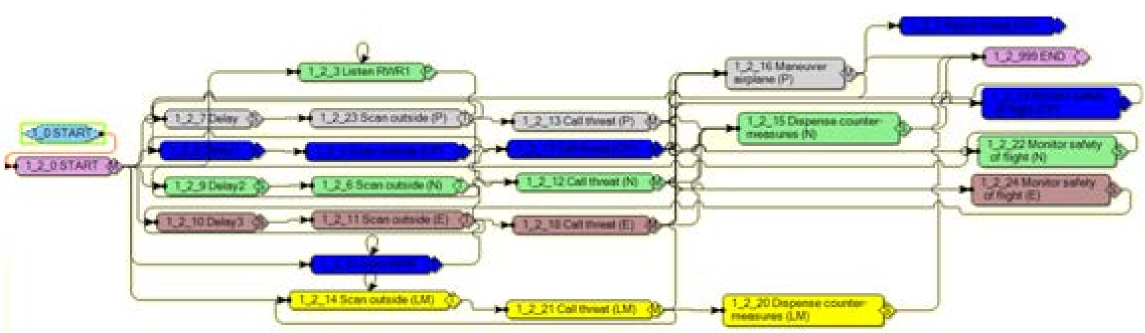

Figure 44: Scan for Threats Function (C-130H)

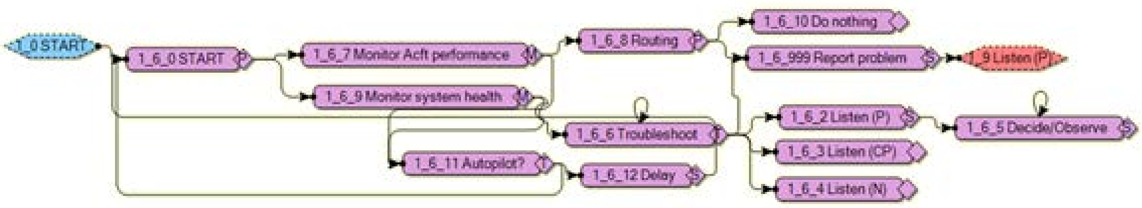

Figure 45: Monitor Systems (E) Function (C-130H)

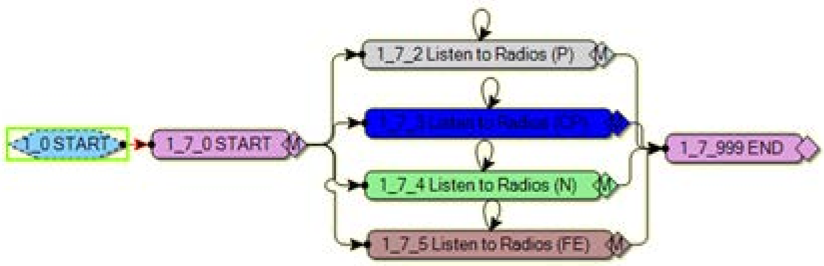

Figure 46: Listen to Radios Function (C-130H)

Figure 47: Control the Airplane (P) Function (C-130H)

C-130J

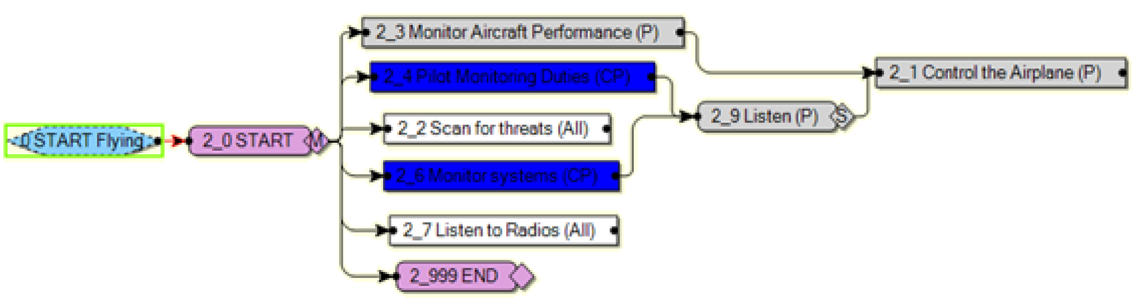

Figure 48: Basic Aircraft Control Task Network (C-130J)

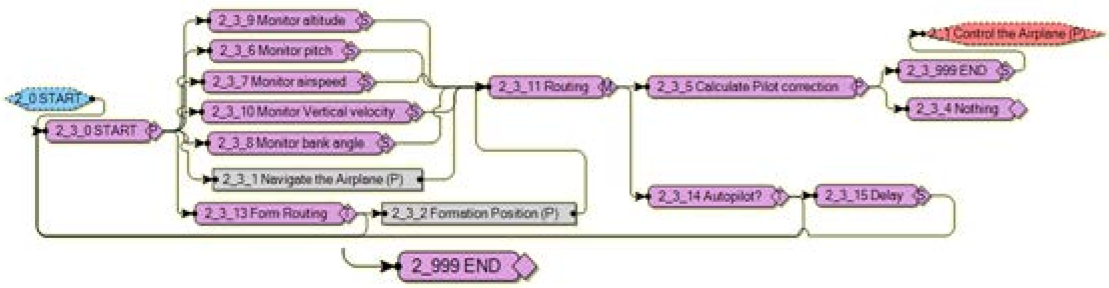

Figure 49: Monitor Aircraft Performance (P) Function (C-130J)

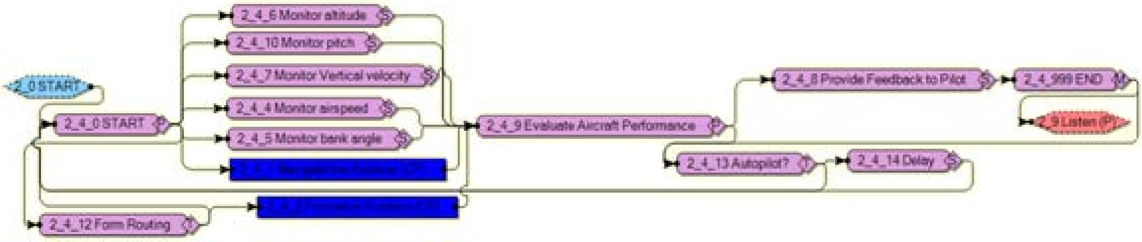

Figure 50: Pilot Monitoring Duties (CP) Function (C-130J)

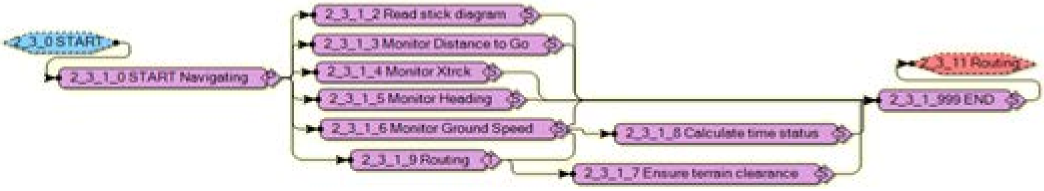

Figure 51: Navigate the Airplane (P/CP) Function (C-130J)

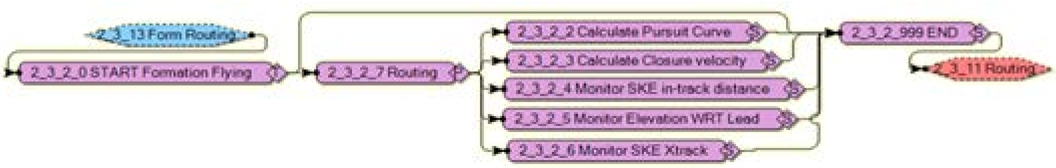

Figure 52: Formation Position (P/CP) Function (C-130J)

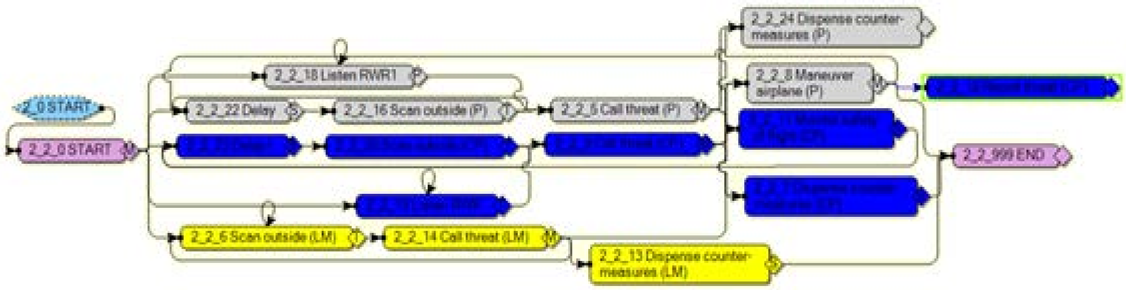

Figure 53: Scan for Threats Function (C-130J)

Figure 54: Monitor Systems (C-130J)

Figure 55: Listen to Radios Function (C-130J)

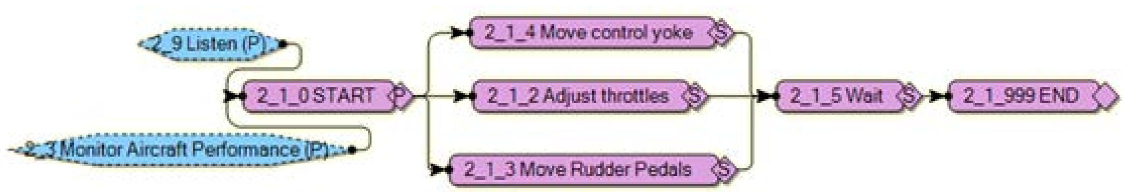

Figure 56: Control the Airplane (P) Function (C-130J)

SKE Formation Airdrop Scenario

C-130H

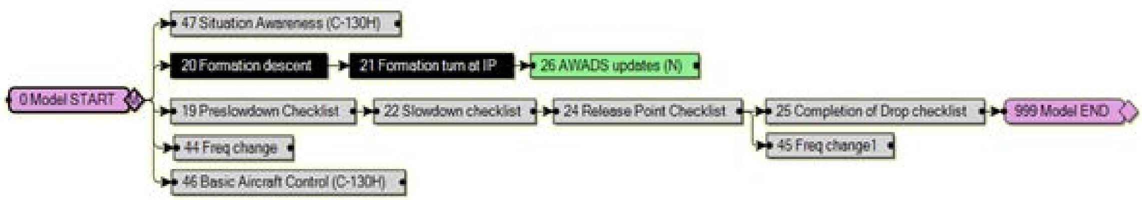

Figure 57: SKE Formation Airdrop Task Network (C-130H)

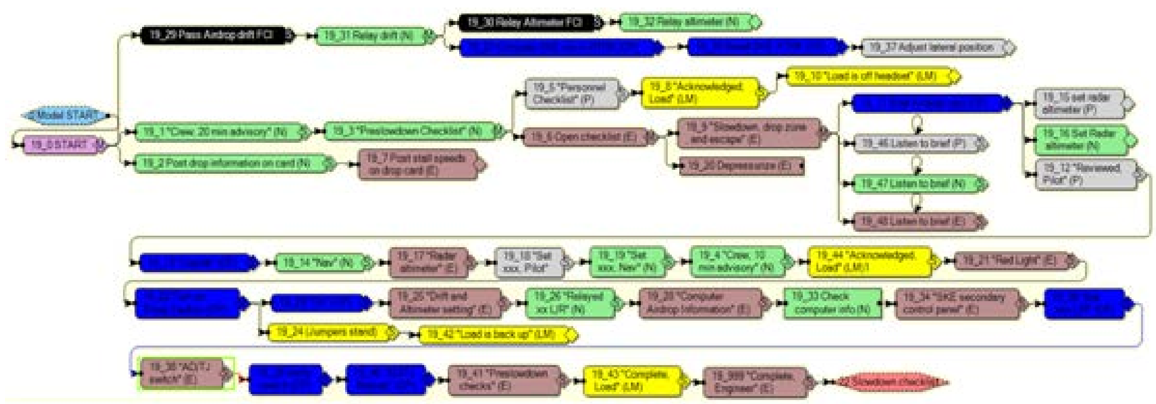

Figure 58: Preslowdown Checklist (C-130H)

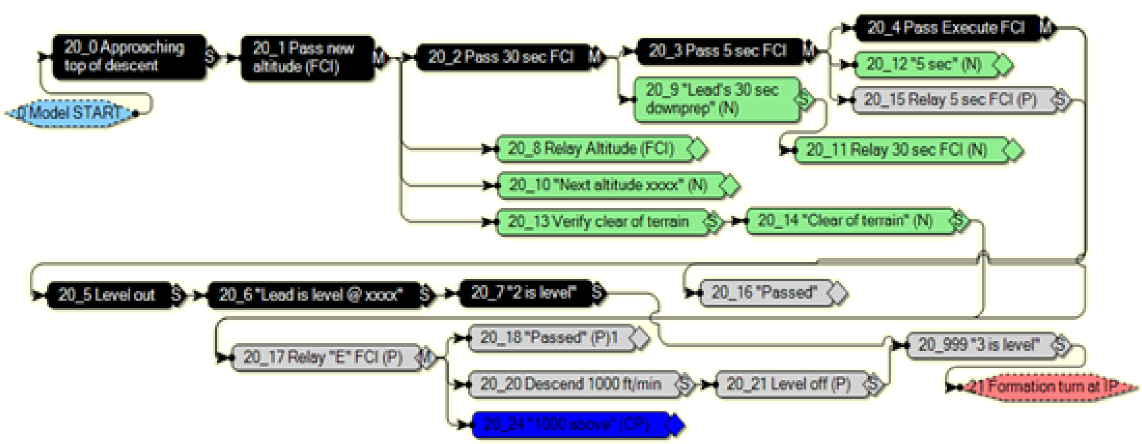

Figure 59: Formation Descent Function (C-130H)

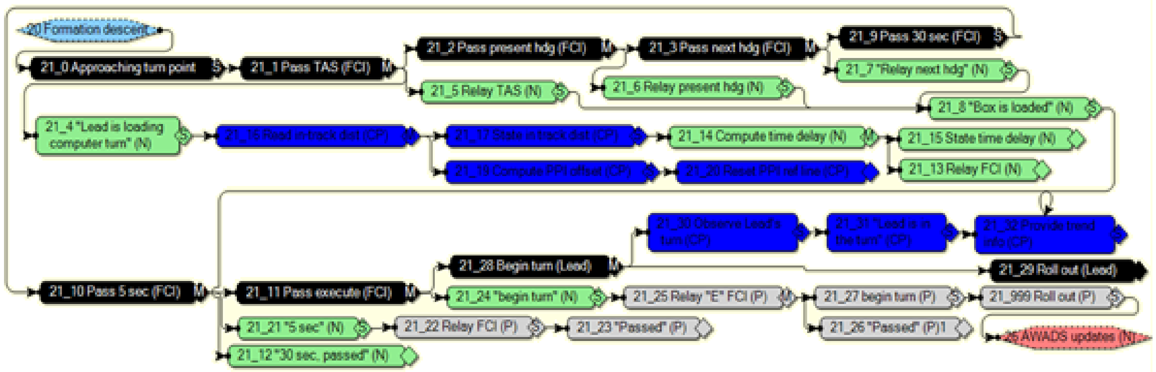

Figure 60: Formation Turn at IP (C-130H)

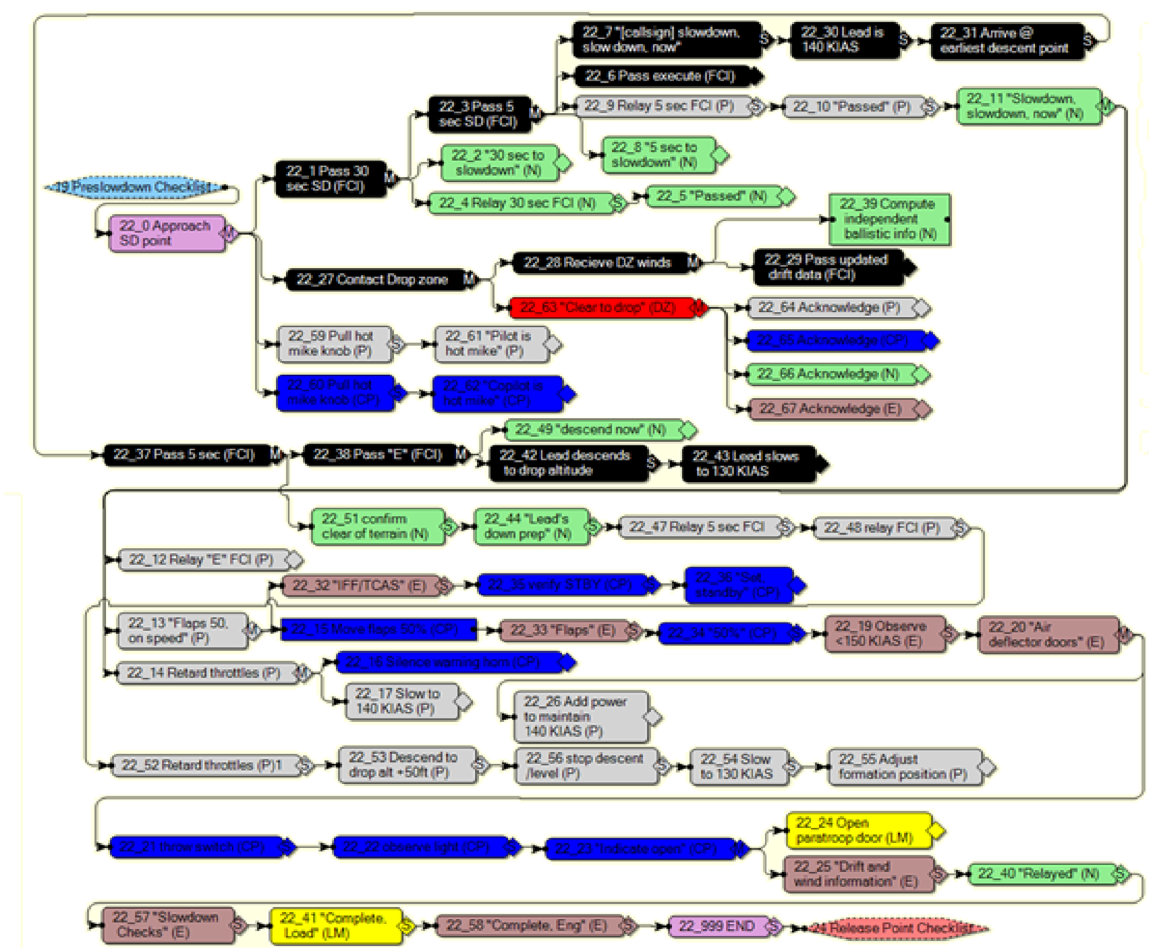

Figure 61: Slowdown Checklist (C-130H)

Figure 62: AWADS Update (N) Function (C-130H)

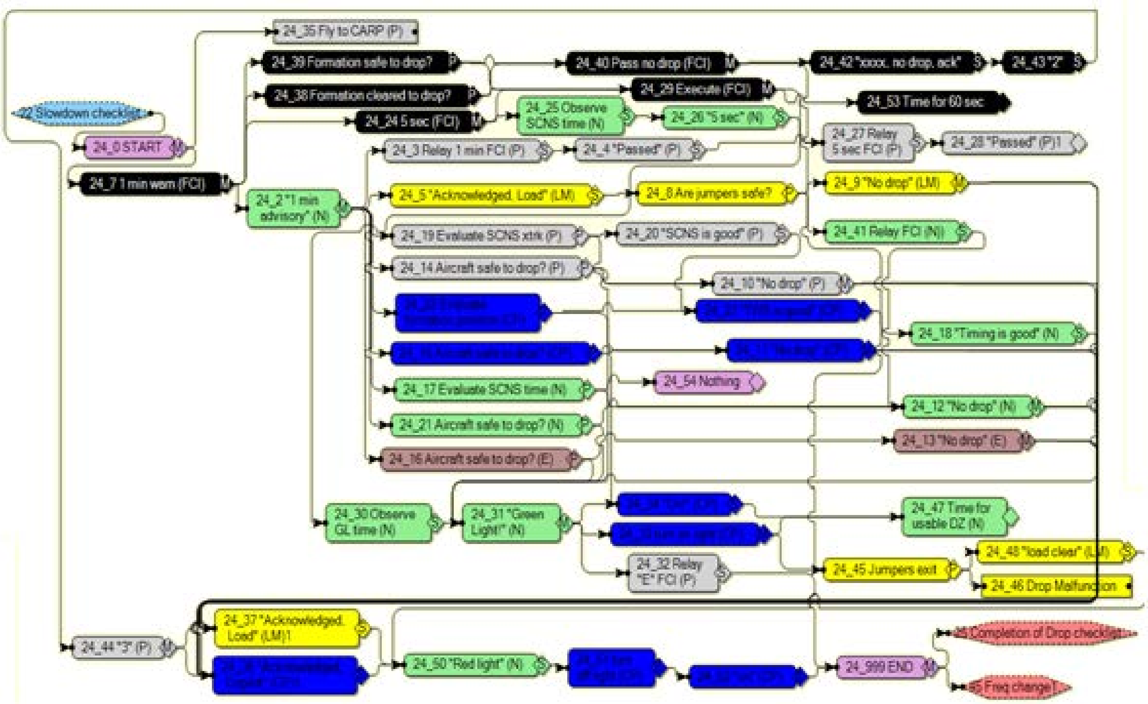

Figure 63: Release Point Checklist (C-130H)

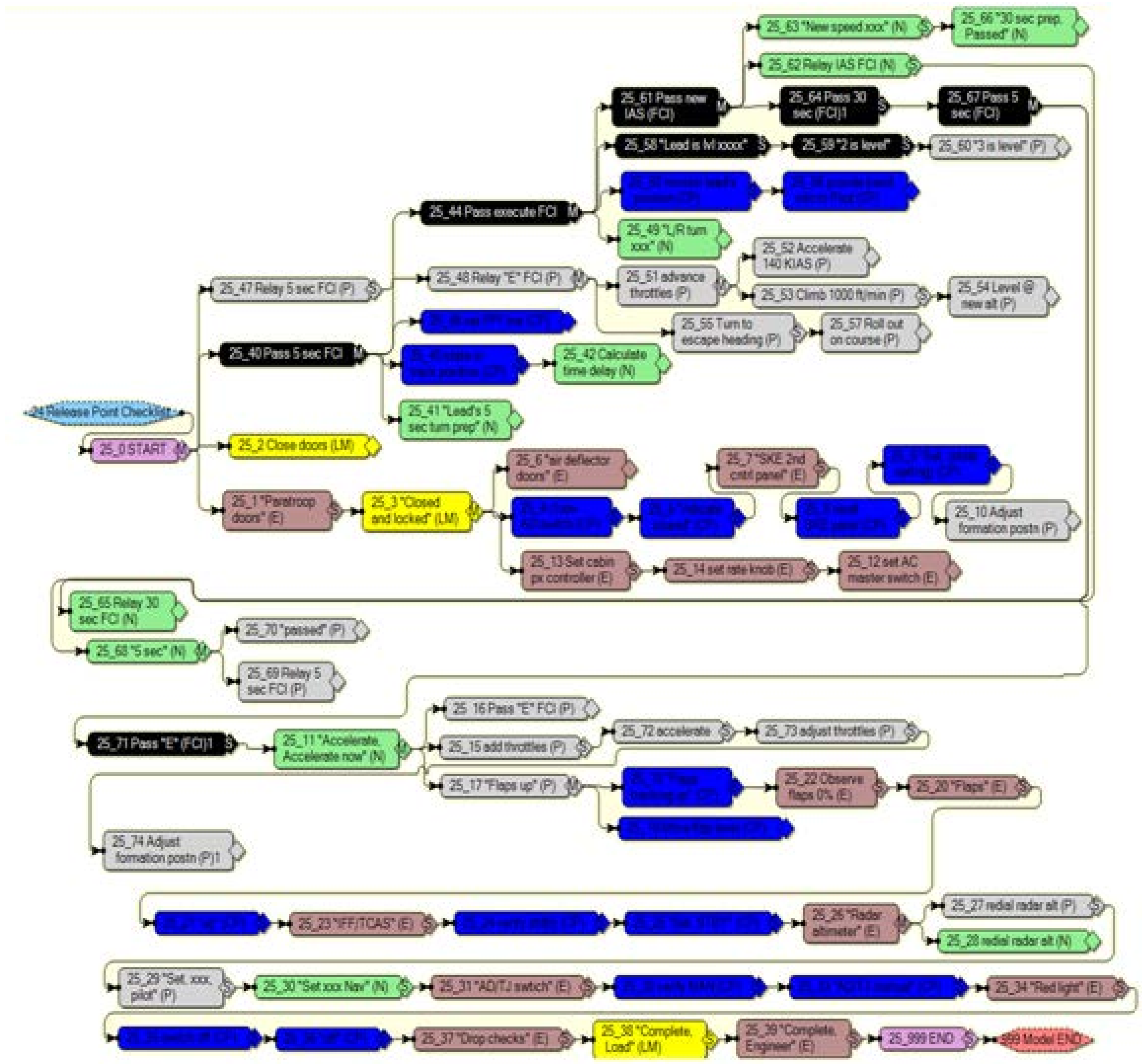

Figure 64: Completion of Drop Checklist (C-130H)

Figure 65: Frequency Change Function (C-130H)

C-130J

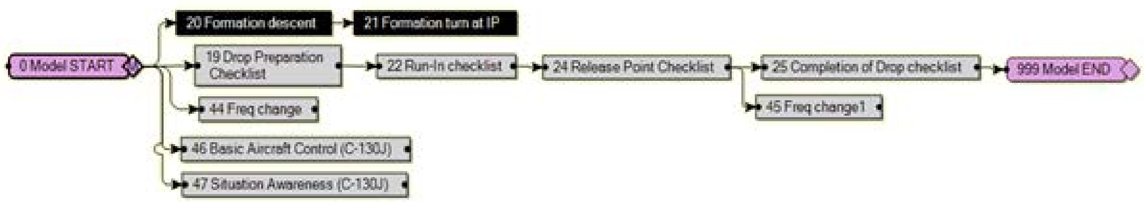

Figure 66: SKE Formation Airdrop Task Network (C-130J)

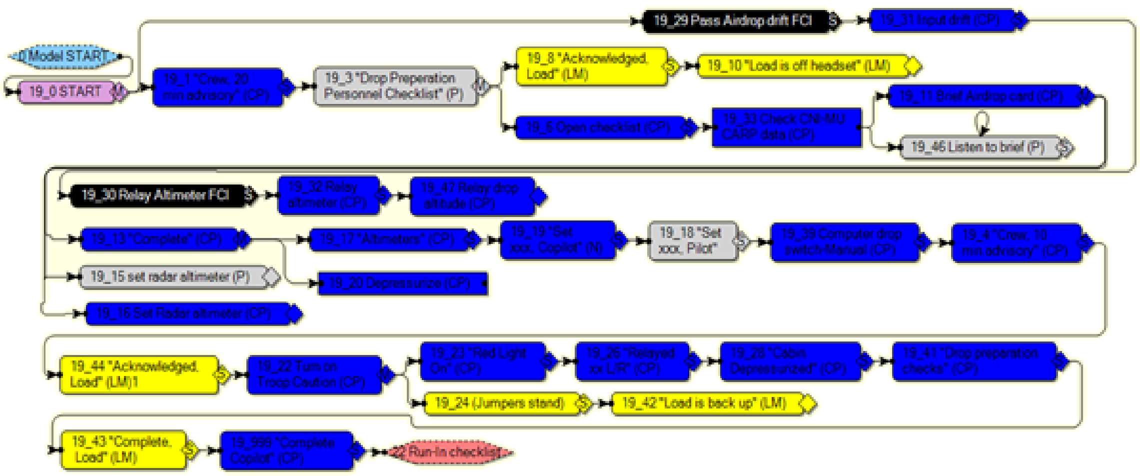

Figure 67: Drop Preparation Checklist (C-130J)

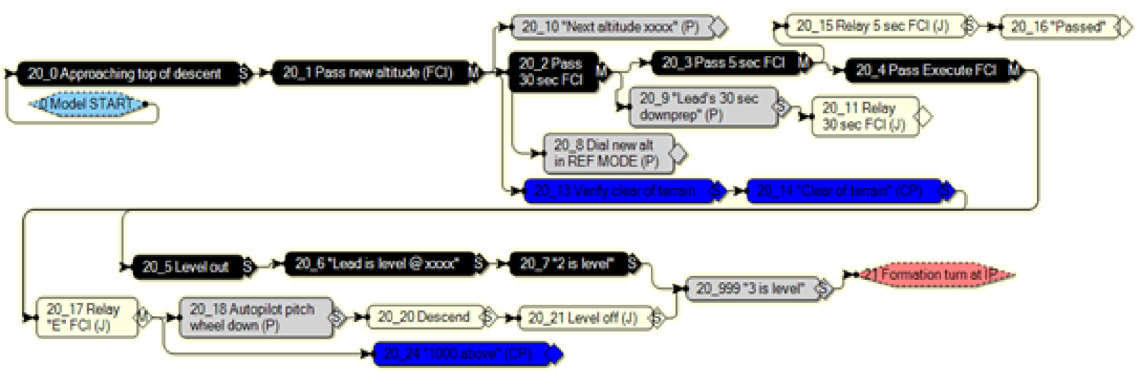

Figure 68: Formation Descent Function (C-130J)

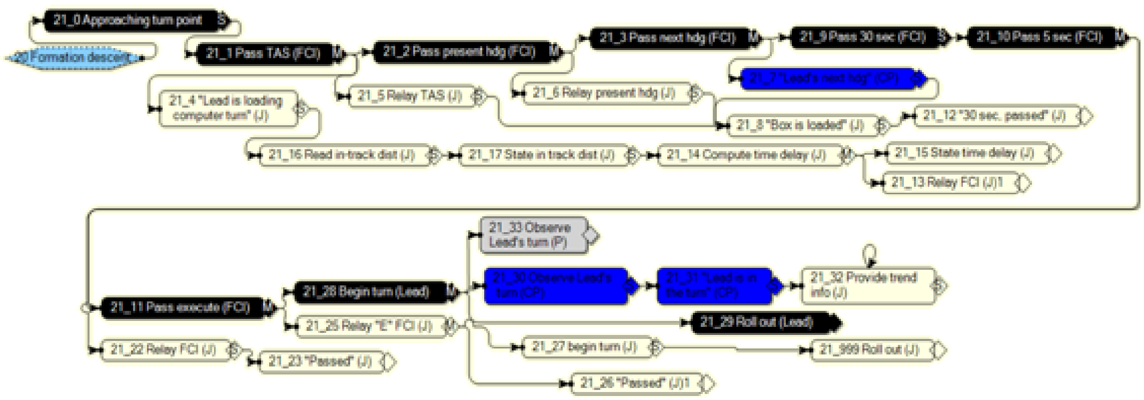

Figure 69: Formation Turn at IP (C-130J)

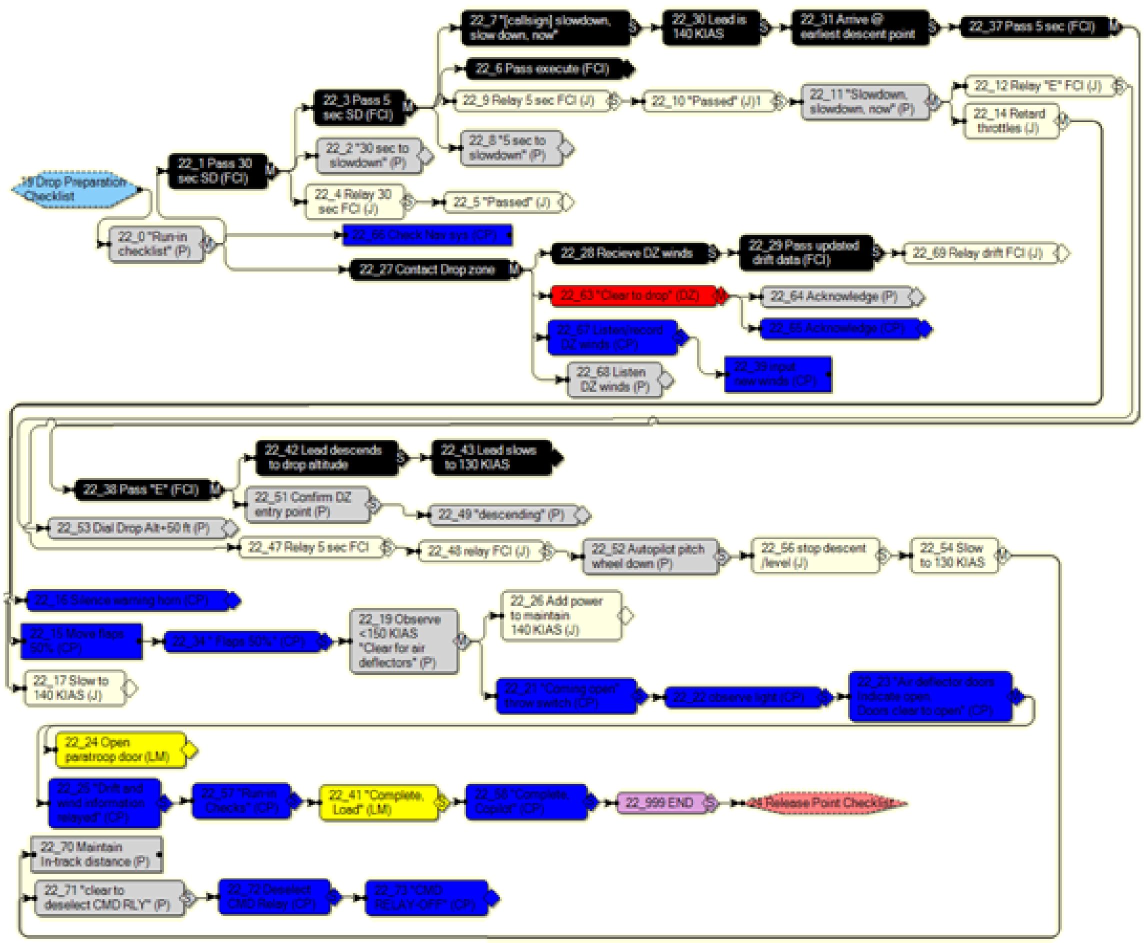

Figure 70: Run-In Checklist (C-130J)

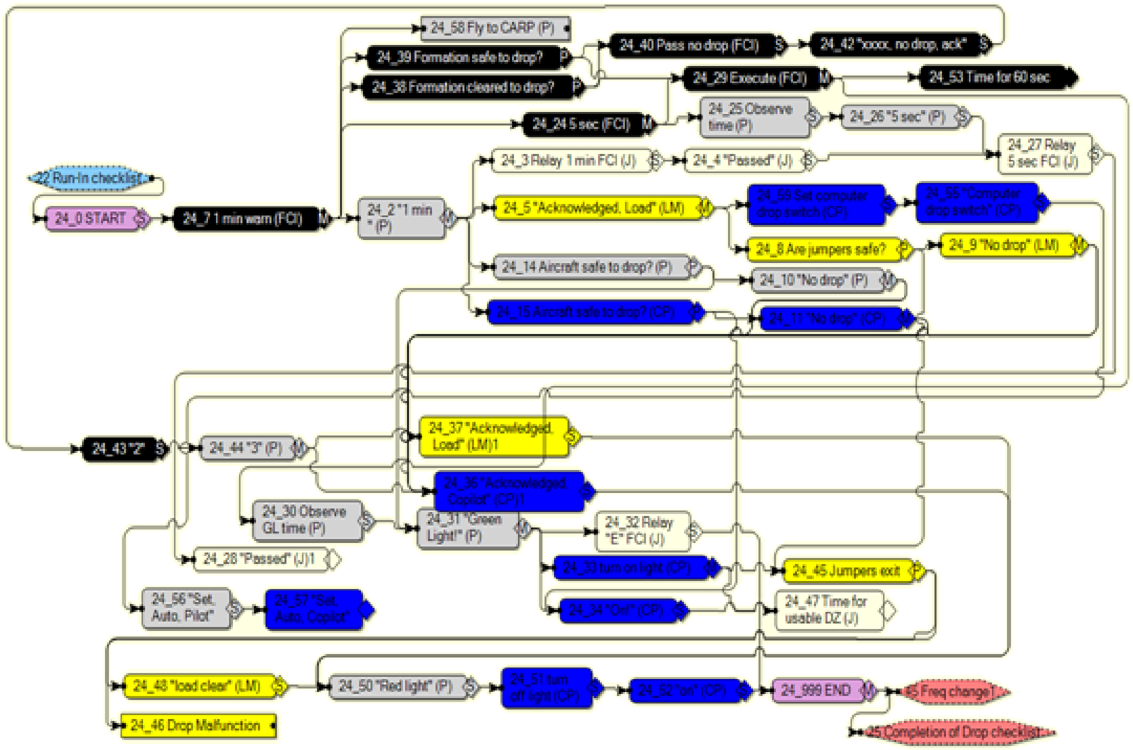

Figure 71: Release Point Checklist (C-130J)

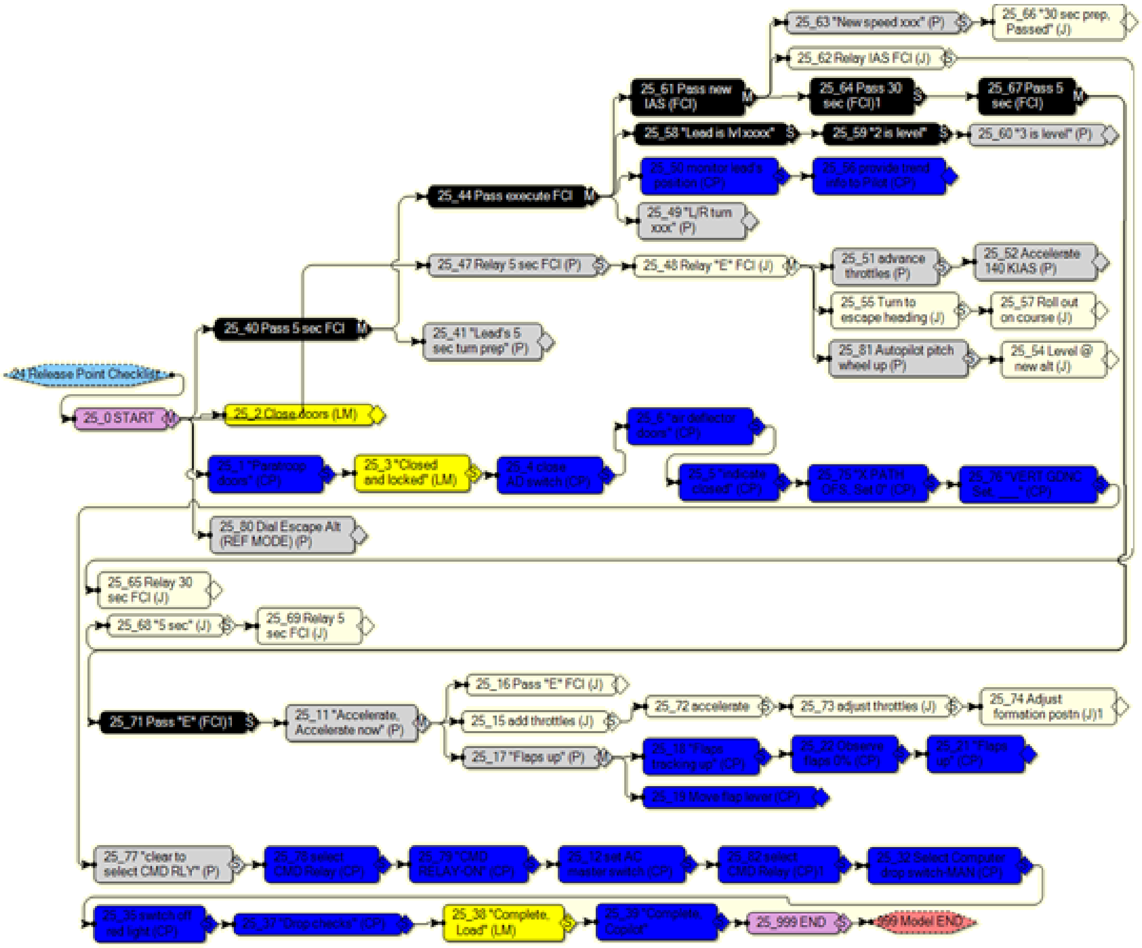

Figure 72: Completion of Drop Checklist

Figure 73: Frequency Change Function (C-130J)

Maximum Effort Airland Scenario

C-130H

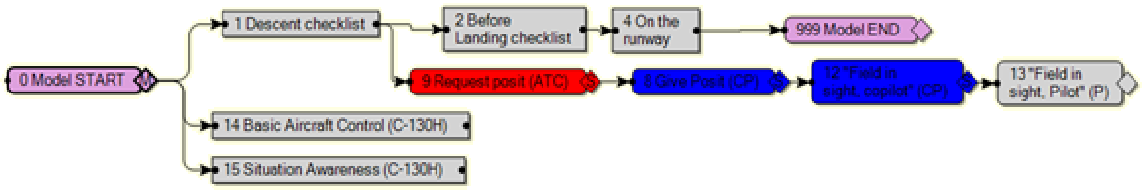

Figure 74: Maximum Effort Airland Task Network (C-130H)

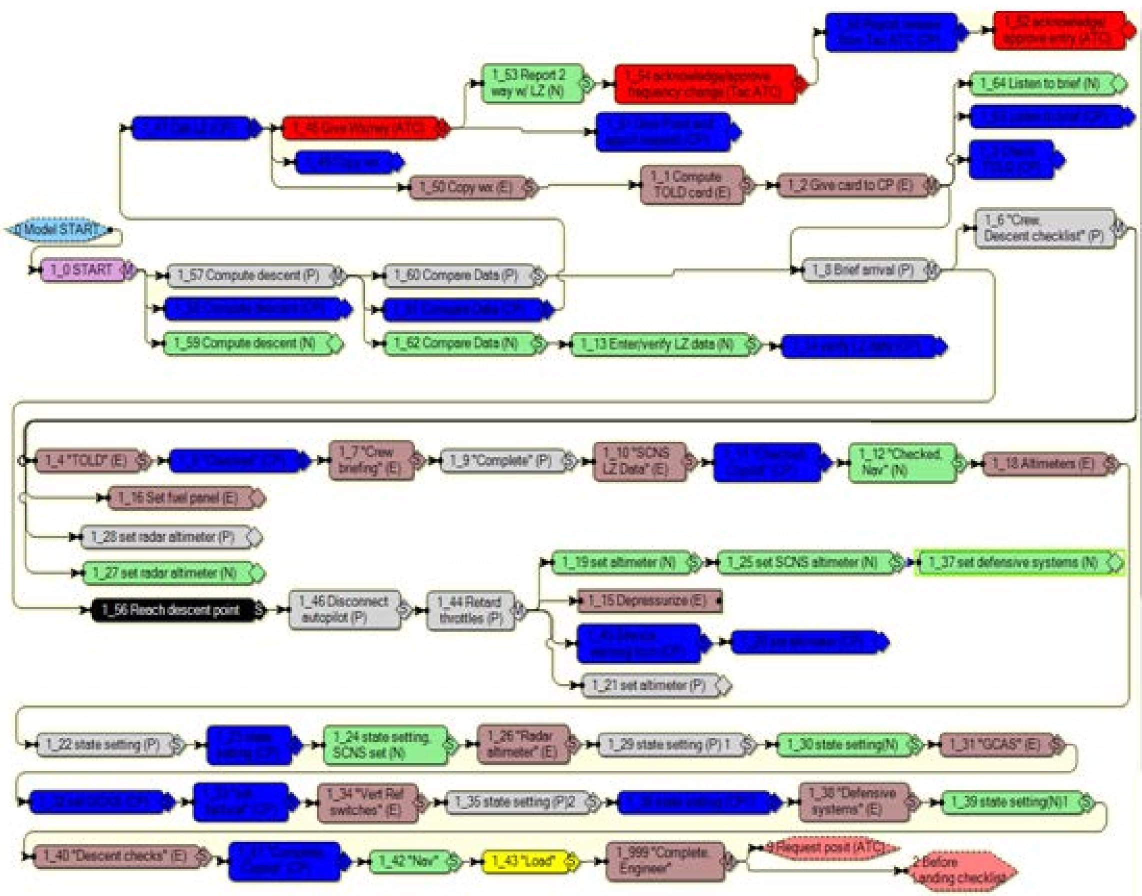

Figure 75: Descent Checklist (C-130H)

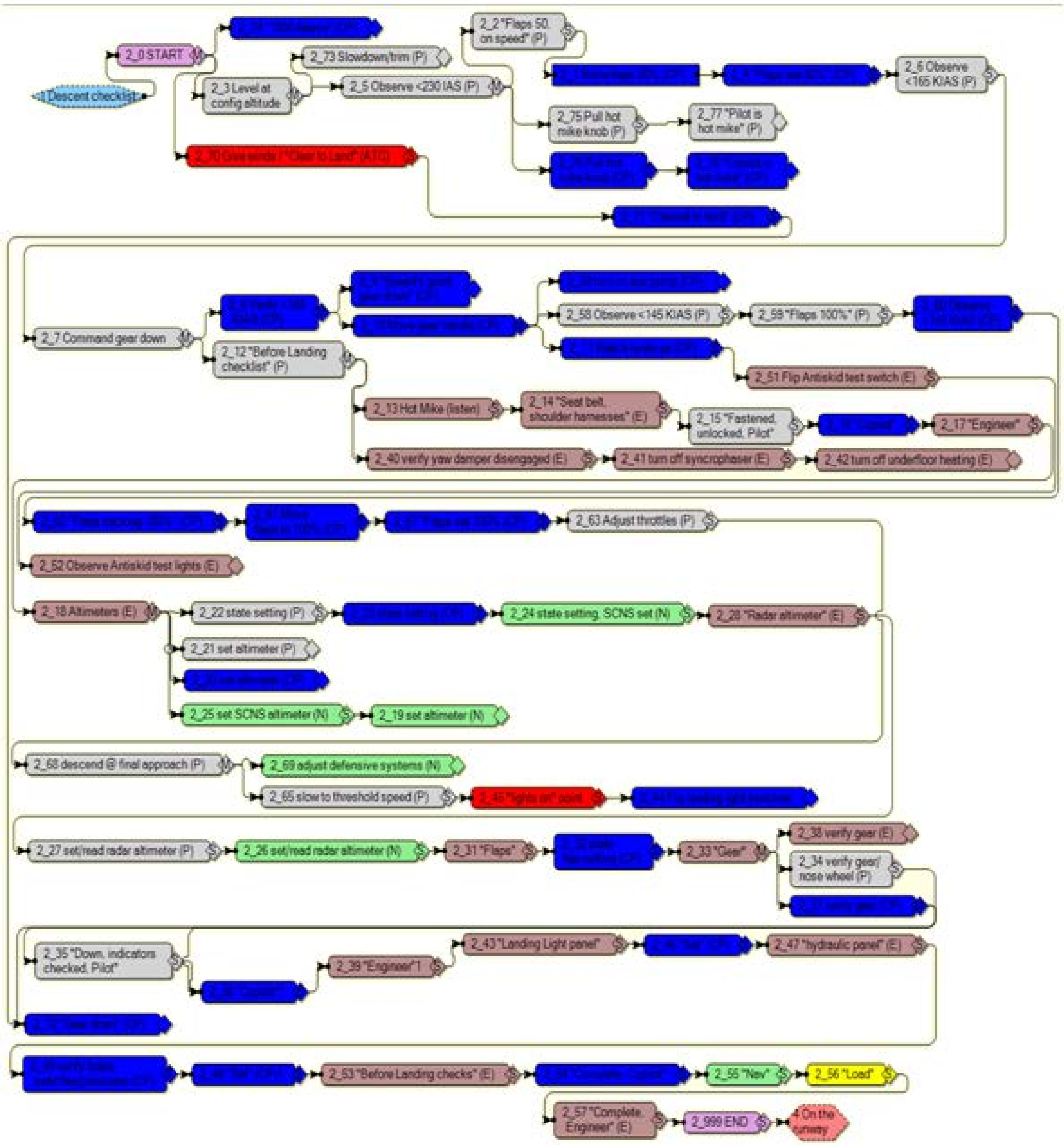

Figure 76: Before Landing Checklist (C-130H)

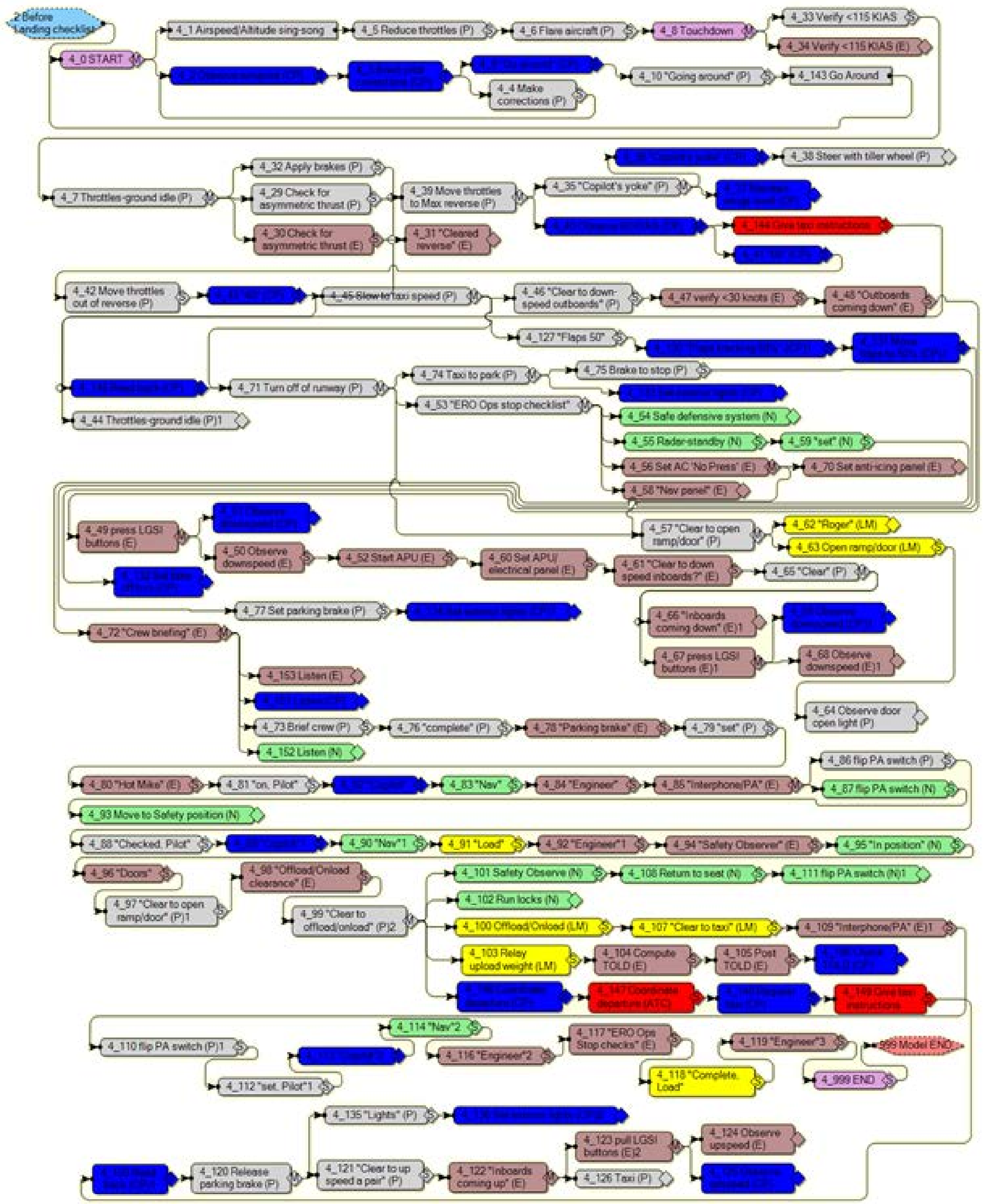

Figure 77: On the Runway Function (C-130H)

C-130J

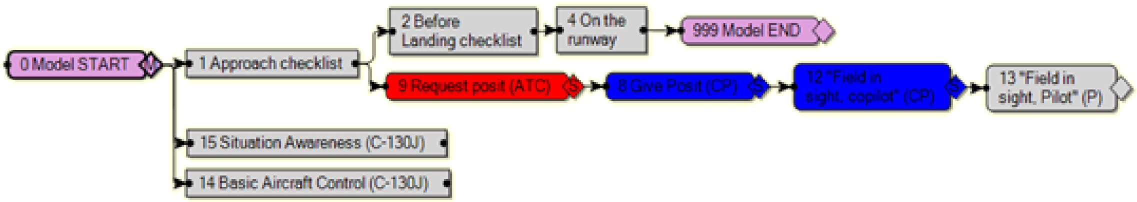

Figure 78: Maximum Effort Airland Task Network (C-130J)

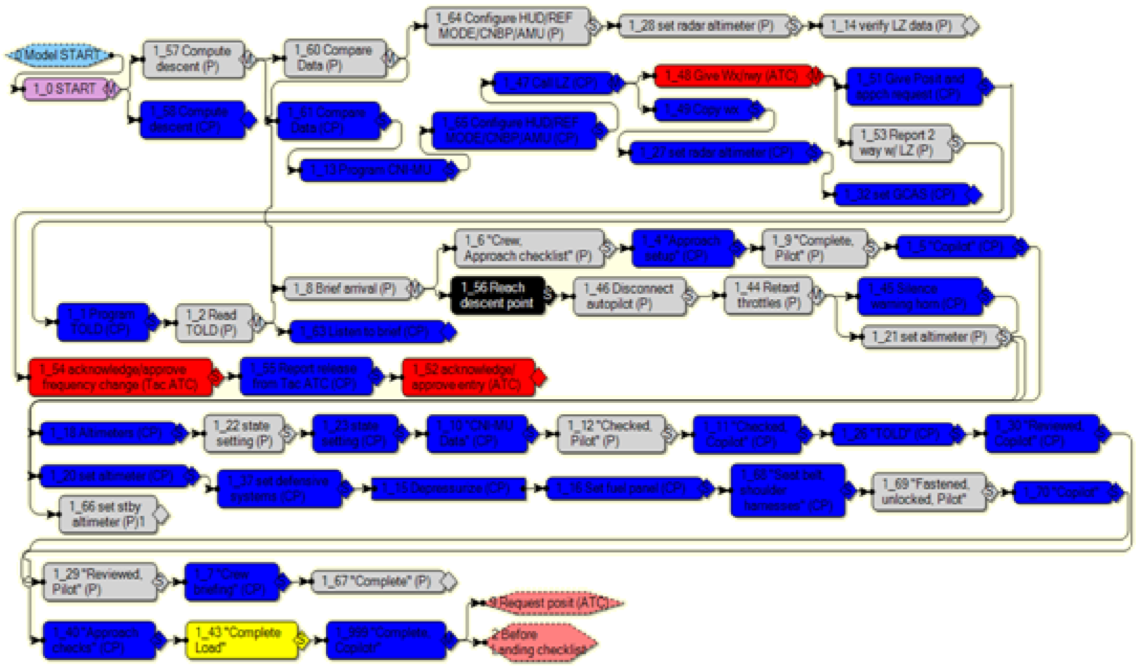

Figure 79: Approach Checklist (C-130J)

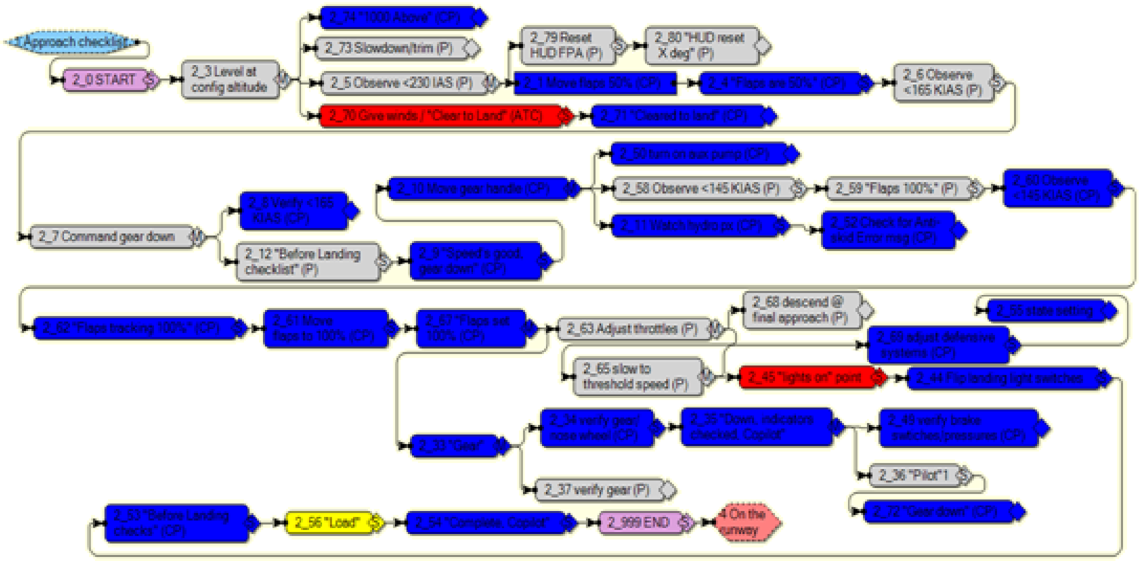

Figure 80: Before Landing Checklist

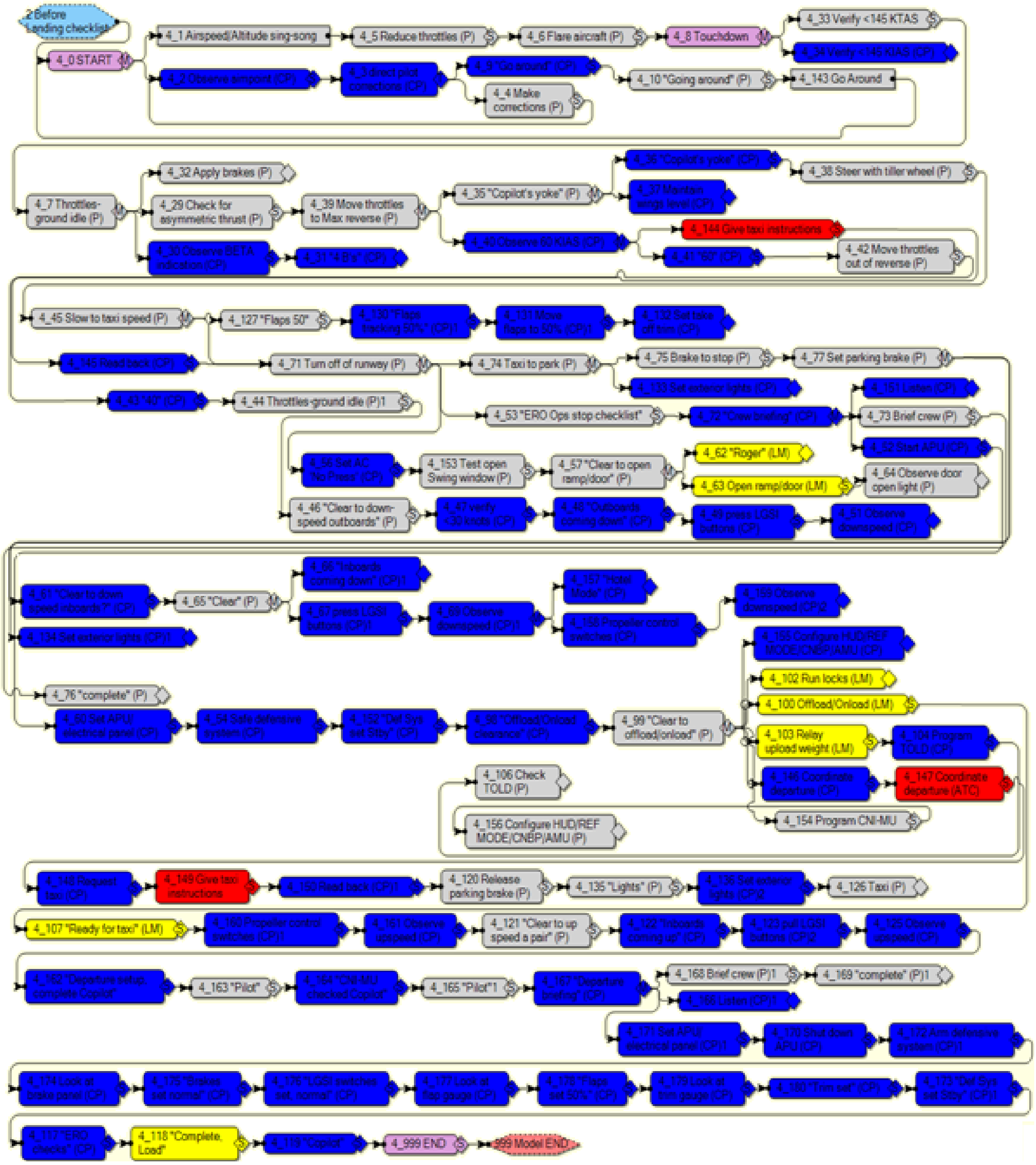

Figure 81: On the Runway Function (C-130J)

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14. ABSTRACT
In tactical aviation, decision superiority brought upon by high situation awareness remains the arbiter of combat effectiveness. The advancement of sophisticated avionics and highly automated cockpits has allowed for the reduction of aircrew size, and in certain platforms, removal of the crew from the aircraft entirely. However, these developments have not reduced the complex and dynamic interaction between situation awareness and crew workload. While many predictive and experimental methods of evaluating workload exist, situation awareness can only be measured by conducting trials with human operators in a functional prototype. This thesis proposes an innovative methodology to predicatively determine situation awareness potential with discrete-event simulation software. This methodology measures situation awareness as both a function of task accomplishment and workload experienced. Utilizing two common but complex tactical scenarios, this method and existing workload measurement techniques can derive a direct comparison between a reduced-crew highly automated cockpit and a less automated "legacy" aircraft. Finally, conclusions regarding the effectiveness of replacing human operators with automation in tactical events can be made and tested in future experiments with actual aircraft and aircrews.

15. SUBJECT TERMS
C-130, workload, situation awareness, pilot, cockpit design, aircrew, discrete event simulation (DES), IMPRINT, station keeping equipment (SKE), airdrop, airland, VACP

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